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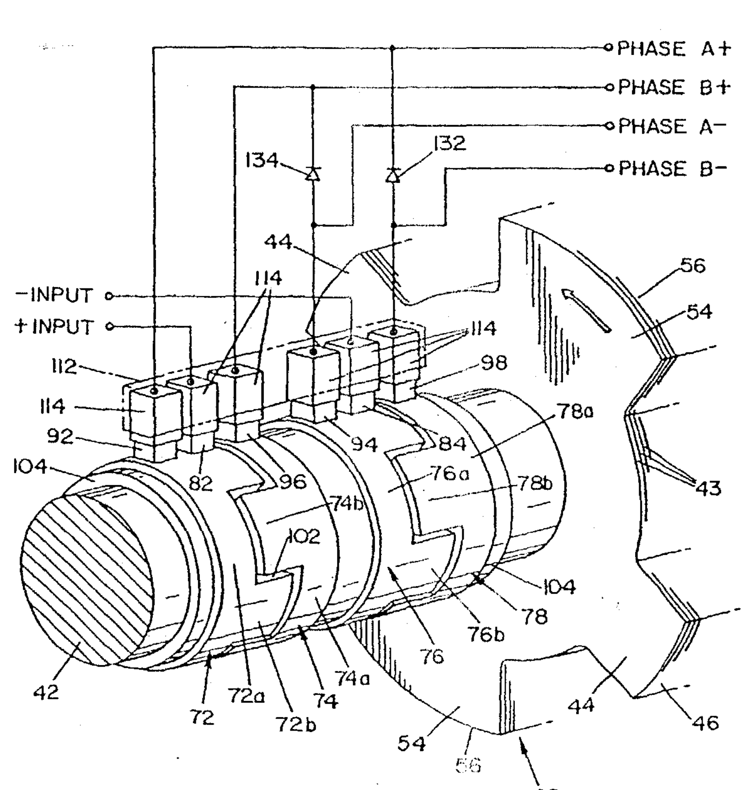
(54) Title: MECHANICALLY COMMUTATED SWITCHED RELUCTANCE MOTOR



(57) Abstract: A switched reluctance motor (10), having a stator (20) with poles (24) defining a gap (28) between adjacent stator poles (24). Windings (32a, 32b) for two phases are wound about the stator poles (24) such that windings (32a, 32b) and stator poles (24) of one phase are circumferentially separated by a winding and an associated stator pole (24) of the other phase. Each phase has a positive and negative terminal (114) energizing the respective windings (32a, 32b) of a phase. A rotor element (40) having a plurality of spaced apart rotor poles (44), is mounted for rotation relative to the stator (20). The motor poles (44) are dimensioned such that energization of one of the phases causes a predetermined angular rotation of the rotor (40). Conductive elements (72, 74, 76, 78) are rotatable with the rotor (40) and are electrically connected to the positive and negative terminals (114) of the phase windings. Power leads (82, 84) connected to an electrical power source (150) engage the conductive elements (72, 74, 76, 78) to alternately energize the first phase and second phase during rotation.

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

MECHANICALLY COMMUTATED SWITCHED RELUCTANCE MOTOR

Field of the Invention

The present invention relates generally to switched reluctance motors, and more particularly to a mechanically commutated switched reluctance motor.

Background of the Invention

U.S. Patent No. 5,852,334 to Pengov discloses a two-phase switched reluctance motor. One embodiment of the motor shows a rotor having two wide rotor poles and two narrow rotor poles. During each phase energization, the rotor is sequentially advanced in a two-step fashion, wherein during a first step, the leading edges of the wide rotor poles interact with a first pair of energized stator poles. During the second step, the narrow rotor poles are drawn into alignment with a second pair of energized stator poles. An electronic controller is used to control the firing of the respective phases of the motor and for adjusting the rotational speed of the rotor.

In many instances, the electronic controller constitutes a major portion of the cost of a motor of the type disclosed in U.S. Patent No. 5,852,334. In some applications, the ability to electronically control the timing of phase energization may not be required, and a fixed speed motor, or a motor wherein the speed may be adjusted by controlling the applied voltage, may be sufficient.

The present invention provides a mechanically commutated switched reluctance motor that eliminates the need for an electronic controller.

Summary of the Invention

In accordance with the present invention, there is provided a switched reluctance motor, comprised of a stator having a plurality of spaced apart, radially oriented, like stator poles that define a gap between adjacent stator poles. Windings for two phases are wound about the stator poles such that windings and stator poles of one phase are circumferentially separated by a winding and an associated stator pole of the other phase. Each phase has a positive and negative terminal for energizing the respective windings of such phase. A rotor element is mounted for rotation relative to the stator. The rotor element has a wide rotor pole having a wide rotor pole face and a narrow rotor pole having a narrow rotor pole face. The rotor poles are dimensioned such that energization of one of the phases causes a predetermined angular rotation of the rotor wherein a first portion of the angular rotation is created by a wide rotor pole

being drawn into a minimum reluctance position relative to one of said energized stator poles and the other portion of the angular rotation is created by a narrow rotor pole being drawn into a minimum reluctance position with another of the energized stator poles, the wide rotor pole being in a minimum reluctance position when the narrow rotor pole is in a minimum reluctance position. Conductive elements are rotatable with the rotor. The elements are electrically connected to the positive and negative terminals of the phase windings. Power leads engage the conductive elements to alternately energize the first phase and second phase as the rotor rotates.

In accordance with the present invention, there is provided a switched reluctance motor, comprised of a stator having a plurality of spaced apart, radially oriented, like stator poles that define a gap between adjacent stator poles. Windings for a first phase and a second phase are wound about stator poles that are circumferentially separated by a winding and an associated stator pole of a different phase. A rotor element is mounted for rotation relative to the stator. The rotor element has a wide rotor pole having a wide rotor pole face and a narrow rotor pole having a narrow rotor pole face. The rotor poles are dimensioned such that energization of one of the phases causes a predetermined angular rotation of the rotor wherein a first portion of the angular rotation is created by the wide rotor pole being drawn into a minimum reluctance position relative to one of the energized stator poles and the other portion of the angular rotation is created by the narrow rotor pole being drawn into a minimum reluctance position with another of the energized stator poles, the wide rotor pole being in a minimum reluctance position when the narrow rotor pole is in a minimum reluctance position. A pair of power brushes is connectable to the leads of a power source. A pair of first phase pick-up brushes is connected to the windings of the first phase in a manner to energize the same. A pair of second phase pick-up brushes is connected to the windings of the second phase in a manner to energize the same. First phase and second phase connector plates are mounted to the rotor for rotation therewith. The connector plates are dimensioned and disposed relative to the power brushes and the pick-up brushes to mechanically commutate the first and second phase windings.

In accordance with another aspect of the present invention, there is provided a switched reluctance motor, comprised of a stator having a plurality of spaced apart, radially oriented, like stator poles. Windings for a first phase and a second phase are

wound about stator poles that are circumferentially separated by a winding and an associated stator pole of a different phase. A rotor is mounted for rotation relative to the stator. The rotor has a plurality of spaced apart rotor poles. The rotor poles are dimensioned such that energization of one of the phases causes a predetermined angular rotation of the rotor. A pair of power brushes is connectable to the leads of a power source. A pair of first phase pick-up brushes is connected to the windings of the first phase in a manner to energize the same. A pair of second phase pick-up brushes is connected to the windings of the second phase in a manner to energize the same. First phase and second phase connector plates are mounted to the rotor for rotation therewith. The connector plates are dimensioned and disposed relative to the power brushes and the pick-up brushes to mechanically commutate the first and second phase windings.

In accordance with another aspect of the present invention, there is provided a switched reluctance motor, comprised of a stator having a plurality of spaced apart, radially oriented, like stator poles. Windings for an "N" number of phases are wound about said stator poles. A rotor is mounted for rotation relative to the stator. The rotor has a plurality of rotor poles. The rotor poles are dimensioned such that energization of each of the N number of phases causes a predetermined angular rotation of the rotor. A pair of stationary power brushes is connectable to leads of a power source. A pair of stationary phase pick-up brushes is provided for each phase of the N number of phases. The pick-up brushes are connected to the respective windings of the phase in a manner to energize the same. A pair of connector plates is provided for the each phase. The connector plates are mounted to the rotor for rotation therewith. The pair of connector plates are disposed relative to the power brushes and the pick-up brush so as to electrically connect the power brushes with the pick-up brush to produce a current path through the winding of the each phase when in the rotor is at specific angular positions.

It is an object of the present invention to provide a mechanically commutated switched reluctance motor.

These and other objects and advantages will become apparent from the following description of a preferred embodiment taken together with the accompanying drawings and the appended claims.

Brief Description of the Drawings

The invention may take physical form in certain parts and arrangement of parts, a preferred embodiment of which will be described in detail in the specification and illustrated in the accompanying drawings which form a part hereof, and wherein:

FIG. 1 is a pictorial view of a mechanically commutated switched reluctance motor, illustrating a preferred embodiment of the present invention;

FIG. 2 is a partially sectioned end view of the motor shown in FIG. 1 taken along lines 2-2 of FIG. 4;

FIG. 3 is an enlarged, partially sectioned end view of the motor shown in FIG. 1 taken along lines 3-3 of FIG. 4, showing a power brush in cross-section;

FIG. 4 is an enlarged side view of a rotor shaft and mechanical commutation assembly;

FIG. 5 is a schematic illustration of a circuit for mechanically commutating a two-phase motor in accordance with the present invention, showing phase B energization;

FIG. 6 is a schematic illustration of a circuit for mechanically commutating a two-phase motor in accordance with the present invention, showing phase A energization;

FIG. 7 is a schematic illustration of a circuit for mechanically commutating a two-phase motor in accordance with the present invention, showing simultaneous energization of phase A and phase B;

FIG. 8 is a schematic illustration of a circuit for mechanically commutating a two-phase motor in accordance with the present invention, showing energization of phase B with the beneficial induced current through phase A applied to phase B;

FIG. 9 is a graph illustrating the phase energization sequence for the mechanical commutation assembly shown in FIGS. 1-7;

FIG. 10 is a graph showing torque versus rotor position for the mechanically commutated motor shown in FIGS. 1-7;

FIG. 11 is an enlarged view of a power brush and commutation assembly, illustrating an alternate embodiment of the present invention;

FIG. 12 is a graph illustrating the phase energization sequence for the mechanical commutation assembly shown in FIG. 11;

FIG. 13 is a graph showing torque versus rotor position for a motor mechanically commutated by the assembly shown in FIG. 11; and

FIG. 14 is a partially sectioned end view of a switched reluctance motor, illustrating another embodiment of the present invention.

Detailed Description of Preferred Embodiment

Referring now to the drawings wherein the showings are for the purpose of illustrating a preferred embodiment of the invention only, and not for the purpose of limiting same, FIG. 1 shows a perspective view of a mechanically commutated, two-phase switched reluctance motor 10, illustrating a preferred embodiment of the invention. Motor 10 is an 8/4 motor of a type disclosed in U.S. Patent No. 5,852,334 to Pengov, the disclosure of which is expressly incorporated herein by reference. Broadly stated, motor 10 has a stator with eight stator poles and a rotor with four rotor poles. The rotor includes two wide rotor poles and two narrow rotor poles. The wide rotor poles are diametrically opposed to each other (as are the narrow rotor poles) and extend along the entire axial length of the rotor. As described in greater detail in U.S. Patent No. 5,852,334, during each phase energization, four of the eight stator poles are energized. Energization of one phase causes the rotor to rotate in a two-step manner. The first step or portion of the angular rotation is created by the leading half of the two diametrically opposed wide rotor poles moving into a minimum reluctance relationship with a pair of diametrically opposed energized stator poles. The second half or portion of the angular rotation of the rotor is created as two narrow rotor poles interact with the remaining two opposed energized stator poles.

Referring now to the present invention, motor 10 is comprised of a stator 20 and a rotor 40. Stator 20 is comprised of a stack of plate laminations 22 (best seen in FIG. 4) that are formed of a ferromagnetic material. Laminations 22 are stacked face-to-face and suitably adhered to one another by means conventionally known in the art. Stator 20 includes a plurality of like, inwardly extending stator poles 24 having inwardly facing concave stator pole faces 26. In the embodiment shown, stator 20 has eight (8) stator poles, designated 24a, 24b, 24c, 24d, 24e, 24f, 24g and 24h. A gap 28 is defined between adjacent stator poles 24. Stator pole faces 26 define a central bore 12 for receiving rotor 40. Phase windings 32a, 32b are alternately wound about every other stator pole 24 such that for every stator pole 24 of one polarity there is a corresponding pole of an opposite polarity.

In the embodiment shown, stator poles 24a, 24c, 24e and 24g are connected as A-phase stator poles, and stator poles 24b, 24d, 24f and 24h are connected as B-phase stator poles. As illustrated in FIG. 2, adjacent stator poles 24 have a different phase, and diametrically opposed stator poles 24 have opposite polarities. In the embodiment shown, phase-A windings 32a and phase-B windings 32b are series connected such that current flows through the phase windings only in one direction. It is to be appreciated, however, that the phase windings could be parallel connected, or combination series-parallel connected, to their respective sources of switched current.

Rotor 40 is disposed within central bore 12 defined by stator pole faces 26. Rotor 40 is fixedly mounted onto a rotor shaft 42 for rotation about an axis that is axially aligned with cylindrical bore 12. Like stator 20, rotor 40 is comprised of a stack of plate laminations 43 (best seen in FIG. 4) that are formed of a ferromagnetic material. As best seen in FIGS. 2 and 3, rotor 40 has diametrically opposed narrow rotor poles 44 having narrow rotor pole faces 46, and diametrically opposed wide rotor poles 54 having wide rotor pole faces 56. Narrow rotor pole face 46 is dimensioned to be slightly larger (preferably less than 2 radial degrees) than a stator pole face 26. Wide rotor pole face 56 is dimensioned to be slightly larger than one stator pole face 26 and a gap 28 adjacent thereto. Narrow rotor poles 44 and wide rotor poles 54 are oriented relative to each other such that each narrow rotor pole face is in alignment (i.e., spans) a stator pole face 26 when each wide rotor pole face 56 spans a stator pole face 26 and an adjacent gap 28, as best illustrated in FIGS. 2 and 3.

In accordance with the present invention, rotor 40 is commutated by mechanical means. In the embodiment shown, a mechanical commutation assembly 70, best seen in FIG. 4, is comprised of four commutation rings 72, 74, 76 and 78, a pair of power brushes 82, 84, a pair of A-phase pick-up brushes 92, 94 and a pair of B-phase pick-up brushes 96, 98. In the embodiment shown, commutation rings 72, 74, 76 and 78 are essentially identical to each other and are arranged in complimentary pairs. Since commutation rings 72, 74, 76 and 78 are essentially identical, only commutation ring 72 shall be described in detail, it being understood that such description applies equally to the others. Commutation ring 72 is basically comprised of an annular band 72a having outward extending tabs 72b. (Similarly, commutation rings 74, 76 and 78 have annular bands 74a, 76a and 78a and tabs 74b, 76b and 78b, respectively). In the embodiment shown, commutation ring 72 includes four, equally

spaced, like tabs 72b. Tabs 72b are dimensioned to define like spaces between adjacent tabs 72b wherein two commutation rings may be positioned on rotor shaft 42 adjacent to one another, with the tabs of each respective ring disposed within the spaces of the other ring. As best seen in FIG. 4, commutation ring 72 and commutation ring 74 are arranged in an interlocking, complimentary fashion and commutation ring 76 and commutation ring 78 are arranged in interlocking, complimentary fashion. As shown in the drawings, a gap 102 exists between adjacent tabs 72b, 74b and 76b, 78b.

Rings 72, 74, 76 and 78 are mounted onto rotor shaft 42 of rotor 40. In the embodiment shown, rotor shaft 42 is formed of metal. To electrically isolate rotor shaft 42 from commutation rings 72, 74, 76 and 78, an insulating sleeve 104 is disposed between commutation rings 72, 74, 76 and 78 and metal rotor shaft 42.

Tabs 72b, 74b, 76b and 78b are dimensioned to span a predetermined angular distance. In this respect, the angular dimension of each tab 72b, 74b, 76b, and 78b is related to the angular rotation of rotor 40 during each phase energization. In the embodiment shown, each tab 72b on commutation ring 72 is dimensioned wherein the surface of tab 72b spans an angular dimension equal to about forty-three angular degrees, wherein the open space between adjacent tabs 72b spans about forty-seven angular degrees. Since commutation rings 72, 74, 76 and 78 are essentially identical, tabs 74b, 76b and 78b of commutation rings 74, 76 and 78, also span about forty-three angular degrees, and the space between the respective tabs of a particular commutation ring spans about forty-seven angular degrees. With two rings 72, 74 joined in complimentary fashion as shown in FIGS. 1 and 4, gap 102 spans about two angular degrees between a tab 72b on commutation ring 72 and a tab 74b on commutation ring 74. As will be described in greater detail below, the angular dimensions of the tabs and the spaces therebetween may vary.

Referring now to power brushes 82, 84, A-phase pick-up brushes 92, 94 and B-phase pick-up brushes 96, 98, each brush is essentially the same and is comprised of a conductive bar that is biased toward a commutation ring on rotor shaft 42. In the embodiment shown, brushes 82, 84, 92, 94, 96 and 98 are conductive bars, such as carbon or metal, of square cross-section. (It will, of course, be appreciated that the cross-sectional shape of the brushes is not critical, and the brushes may have other cross-section shapes such as rectangular, oval, round, triangular or the like, without

deviating from the present invention). In the embodiment shown, brushes 82, 84, 92, 94, 96 and 98 are mounted within a single housing 112 that is shown in phantom in FIG. 4. Housing 112 is formed of a non-conductive material to electrically isolate one brush from another. Each brush 82, 84, 92, 94, 96 and 98 is basically mounted within a conductive sleeve 114 in like fashion, as shall now be described. Each conductive sleeve 114 has a generally square cross-section and a closed bottom. Sleeve 114 defines a cylindrical opening that is slightly larger than brush 82 to slidably receive brush 82 therein. A biasing spring 122 is disposed within the opening of sleeve 114 between the bottom thereof and brush 82. Biasing spring 122 is operable to bias brush 82 toward rotor shaft 42, and into engagement with tabs 72b, 74b of commutation rings 72, 74. An electrical wire is connected to brush 82 and sleeve 114. Brushes 84, 92, 94, 96 and 98 are mounted within housing 112 in a similar fashion, and are positioned relative to commutation rings 72, 74, 76 and 78, to engage select portions thereof.

As schematically illustrated in FIG. 4, the connector wire connects power brush 82 to the positive lead of a power source (not shown). In a similar fashion, a connector wire connects to negative power brush 84 to the negative lead of the power source. Wire leads connect A-phase pick-up brushes 92, 94 to respective opposite ends of phase-A windings 32a, and also connect B-phase pick-up brushes 96, 98 to the respective opposite ends of the phase-B windings 32b, as illustrated in FIGS. 3 and 4.

As shown in FIG. 4, power brushes 82, 84, A-phase pick-up brushes 92, 94 and B-phase pick-up brushes 96, 98 are disposed adjacent to commutation rings 72, 74, 76 and 78 at specific locations with respect thereto. Positive power brush 82, A-phase pick-up brush 92 and B-phase pick-up brush 96 are disposed adjacent rings 72, 74 to form a "positive commutation grouping." Specifically, A-phase pick-up brush 92 is disposed to engage annular band portion 72a of commutation ring 72. B-phase pick-up brush 96 is disposed to engage band portion 74a of commutation ring 74. Positive power brush 82 is positioned to engage tabs 72b, 74b of commutation rings 72, 74.

Negative power brush 84, A-phase pick-up brush 94 and B-phase pick-up brush 98 are disposed adjacent to commutation rings 76, 78 to form a "negative commutation grouping." Specifically, A-phase pick-up brush 94 is disposed to engage annular band portion 76a of commutation ring 76. B-phase pick-up brush 98 is

disposed to engage annular band portion 78a of commutation ring 78. Negative power brush 84 is positioned to engage tabs 76b, 78b of commutation rings 76, 78.

As shown in FIG. 4, a directional diode 132 is connected across the wiring lines connected to A-phase pick-up brush 92 and B-phase pick-up brush 98. A second diode 134 is connected across the wiring lines connected to A-phase pick-up brush 94 and B-phase pick-up brush 96.

Referring now to the operation of motor 10, commutation rings 72, 74, 76 and 78 are mounted for rotation with rotor shaft 42. As shown in FIG. 4, commutation rings 72, 76 and commutation rings 74, 78 are in the same angular position on rotor shaft 42, such that positive power brush 82 and negative power brush 84 will engage the commutation rings 72 and 76 respectively or commutation rings 74, 78 respectively, at the same time. For example, FIG. 4 shows positive power brush 82 in contact with tab 72b of commutation ring 72 while negative power brush 84 is in contact with tab 76b of commutation ring 76. In this position, an electrical circuit is created through phase-A windings 32a. Specifically, current from the power source is conveyed through positive power brush 82 into tab 72b and commutation ring 72. From commutation ring 72, current flows through A-phase pick-up brush 92 to phase-A windings 32a. The current flows through phase-A windings 32a to pick-up brush 94 and to commutation ring 76. The current flows through tab 76b in commutation ring 76 and through it to negative power brush 84 to complete the circuit with the power source.

Similarly, when positive power brush 82 is in contact with a tab 74b of commutation ring 74, and negative power brush 84 is in contact with a tab 78b of commutation ring 78, an electrical circuit is created through phase-B windings 32b.

In accordance with the present invention, the position of commutation rings 72, 74, 76 and 78 on rotor shaft 42 is associated with the position of narrow rotor poles 44 and wide rotor poles 54 on rotor shaft 42. Specifically, commutation rings 72, 74, 76 and 78 are positioned on rotor shaft 42, such that as the leading edges of wide rotor poles 54 are approximately aligned with the edges of two stator poles 24 of one of the two phases, commutation rings 72, 74, 76 and 78 are positioned relative to positive and negative power brushes 82, 84 to energize that phase.

For example, with rotor 40 in the position shown in FIG. 3 and moving in a counter-clockwise direction, power brushes 82, 84 are disposed to be in a position to

begin contact with tabs 74b and 78b, respectively so as to energize the phase-B windings 32b. Energization of phase B produces rotation of rotor 40 in a two-step fashion as briefly described above. (A more specific discussion of the physical operation of motor 10 may be found in U.S. Patent No. 5,852,334). Rotation of rotor 40 produces rotation of rotor shaft 42 which, in turn, causes commutation rings 72, 74, 76 and 78 to move relative to brushes 82, 84, 92, 94, 96 and 98. As commutation rings 72, 74, 76 and 78 rotate with rotor shaft 42, A-phase pick-up brushes 92, 94 are always in contact with annular portions 72a and 76a of commutation rings 72, 76 respectively, and B-phase pick-up brushes 96, 98 are always in contact with annular portions 74a and 78a of commutation rings 74, 78.

However, about when rotor 40 moves into a minimum reluctance position with phase-B windings 32b, stationary power brushes 82, 84 begin to engage A-phase commutation tabs 72b and 76b. For a short period, power brushes 82, 84 are in contact with both B-phase commutation tabs 74b and 78b, and A-phase commutation tabs 72b and 76b. This occurs because power brushes 82, 84 preferably have an angular dimension greater than space 102. As a result, in the embodiment shown in FIGS. 1 through 4, power brushes will contact both A-phase commutation tabs 72b, 76b and B-phase commutation tabs 74b, 78b, for a short period, as illustrated in FIG. 3.

Thus, as rotor 40 moves into minimum reluctance position with phase-B windings 32b, power brushes 82, 84 move from exclusive contact with B-phase commutation tabs 74b and 78b into contact with A-phase commutation tabs 72b and 76b, and B-phase commutation tabs 74b and 78b thereby initiating energization of phase-A windings 32a while maintaining energization of phase-B windings 32b. Further rotation of rotor 40 de-energizes phase-B windings 32b as power brushes 82, 84 move off commutation tabs 74b and 78b into exclusive contact with A-phase commutation tabs 72b and 76b. Associated with the de-energization of B-phase windings 32b is the creation of an induced current as shall be described in greater detail below.

The phase change from B-phase energization to A-phase energization preferably occurs when the leading edges of wide rotor poles 54 approach or slightly overlap the edges of an A-phase stator pole 24. Energization of the phase-A windings 32a, produces continued rotation of rotor 40. As commutation rings 72, 74, 76 and 78

rotate with rotor 40, continued firing of the respective phases is accomplished by the sequential energization of the respective phases as a result of power brushes 82, 84 contacting the alternating commutation tabs associated with the two different phases.

FIGS. 5, 6 and 7 are circuit diagrams of a circuit 200 that schematically illustrates the operation of motor 10. Circuit 200 includes a DC power source 150 for energizing phase-A windings 32a and phase-B windings 32b. Power brushes 82, 84, A-phase pick-up brushes 92, 94 and B-phase pick-up brushes 96, 98 are shown angularly disposed about rotor shaft 42. Circuit 200 illustrates how phase-A windings 32a and phase-B windings 32b are electrically connected to power source 150 via power brushes 82, 84, A-phase pick-up brushes 92, 94 and B-phase pick-up brushes 96, 98, during each phase energization.

FIG. 5 shows how, in one position of rotor shaft 42, commutation rings 74, 78 (schematically shown as arc connectors) on rotor shaft 42 connect, respectively, power brush 82 to B-phase pick-up brush 96 and power brush 84 to B-phase pick-up brush 98 to complete a circuit from power source 150 through phase-B windings 32b to energize the same. The arrows show the current path from power source 150 through phase-B windings 32b. The circuit shown in FIG. 5 is created whenever rotor shaft 42 is in a position where power brushes 82, 84 are in contact with tabs 74b, 78b, respectively, of commutation rings 74, 78.

FIG. 6 shows circuit 200 during energization of phase A. With rotor shaft 42 in a second angular position, commutation rings 72, 76 (also schematically shown as arc connectors) connect respectively, power brush 82 to A-phase pick-up brush 92 and power brush 84 to A-phase pick-up brush 94 to complete a circuit from power source 150 through phase-A windings 32a. The arrow shows the current path from power source 150 through phase-A windings 32a. The circuit shown in FIG. 6 is created whenever rotor shaft 42 is in a position where power brushes 82, 84 are in contact with tabs 72b, 76b, respectively, of commutation rings 72, 76.

In some embodiments of motor 10 (such as that shown in FIG. 4), the cross-sectional dimension of power brushes 82, 84 may be greater than space or gap 102, wherein power brush 82 will simultaneously contact tabs 72b, 74b in certain angular positions of rotor shaft 42. In such instances, the current paths are simultaneously created through phase-A windings 32a and through phase-B windings 32b, as schematically illustrated in FIG. 7.

As one phase is de-energized and the other phase is energized, according to Faraday's Law of Induction, the changing magnetic field experienced by the de-energized windings induces (i.e., creates) a current through such windings. According to Lenz's Law, the direction of the induced current is the same as the direction of the original current that produced the original magnetic field in the now de-energized phase windings.

In accordance with one aspect of the present invention, directional diodes 132, 134 direct current induced in de-energized windings into the windings being energized. In this respect, as shown in FIG. 4, diode 132 is connected between the end of phase-B windings 32b and the beginning of phase-A windings 32a so as to allow current from phase-B windings 32b to flow through phase-A windings 32a. Similarly, directional diode 134 is connected between the end of phase-A windings 32a and the beginning of phase-B windings 32b so as to allow current from phase-A windings 32a to flow into phase-B windings 32b. In operation, current induced in phase-B windings 32b as a result of de-energization of such windings, is directed into phase-A windings 32a while such windings are being energized. Similarly, current induced in phase-A windings 32a caused by the de-energization of such windings, is directed into phase-B windings 32b while such windings are energized.

FIG. 8 schematically illustrates circuit 200 immediately after the de-energization of phase A and the energization of phase B. The energization of phase-B windings 32b produces a current path similar to that illustrated in FIG. 5, wherein current from power source 150 is directed through commutation rings 74 and 78 through windings 32b. At the same time, a current, depicted by wavy arrows, is induced in phase-A windings 32a by the de-energization of such windings. Since A-phase pick-up brushes 92, 94 are no longer directly connected to power brushes 82, 84, the current is directed through diodes 132, 134 to power source 150, and/or phase-B windings 32b. As a result, the induced current is directed from phase-A windings 32a to the positive end of phase-B windings 32b via the circuit line containing directional diode 134. The induced current is thus directed to the energized windings 32b. In a similar manner, current induced in phase-B windings 32b, during de-energization of such windings, is directed to the positive side of phase-A windings 32a via the circuit line containing directional diode 132.

The aforementioned diode arrangement prevents the induced current generated by the de-energization of a phase from being dissipated as heat or from causing arcing as the respective phases are de-energized. As will be appreciated by those skilled in the art, the mechanical commutation system 70 as heretofore described would be operable without directional diodes 132, 134, but the addition of such elements reduces overheating and arcing of the components and extends the life of brushes 82, 84, 92, 94, 96 and 98.

In accordance with the present invention, the angular dimension of commutation tabs 72b, 74b, 76b and 78b is related to the geometry of motor 10. In the embodiment shown, rotor 40 of motor 10 is designed to rotate about forty-five angular degrees per each phase energization. A more detailed description of the operation of the 8/4 motor 10 disclosed in U.S. Patent No. 5,852,334. It is therefore desirable that mechanical commutation assembly 70 be operable to energize each phase to produce the rotation of rotor 40 for forty-five angular degrees. As indicated above, in the embodiment heretofore described, each commutation tab 72b, 74b, 76b and 78b spans about forty-three angular degrees. The two angular degrees difference in between dimensions is to create the necessary separation, i.e., gap 102, between adjacent commutation tabs.

In the embodiment shown in FIGS. 1 through 4, power brushes 82, 84 span about two angular degrees. In this respect, power brushes 82, 84 are about seven angular degrees wider than gap 102. As a result, both phase A and phase B will be energized for about seven angular degrees of rotation of rotor shaft 42 as power brushes 82, 84 slide across gap 102 from one commutation tab to another.

FIG. 9 is a graph showing the energization profile for a motor 10 as heretofore described. FIG. 9 illustrates the periods of simultaneous energization of phases A and B as a result of power brushes 82, 84 simultaneously contacting commutation rings for both phases A and B.

FIG. 10 is a static torque curve for motor 10 as heretofore described. The simultaneous overlap at the beginning of each phase energization reduces torque ripple, as illustrated in FIG. 10.

As will be appreciated by those skilled in the art, the gap or space 102 between adjacent commutation tabs 72b and 74b, or 76b and 78b, may be increased or slightly

decreased (a gap 102 between the commutation tabs must always exist) to adjust or modify the duration of each phase energization.

FIG. 11 shows a mechanical commutation assembly 70' illustrating an alternate embodiment of the present invention. In assembly 70', adjacent commutation tabs 72b', 74b' are dimensioned to define a space or gap 102' of about fifteen angular degrees therebetween. In the embodiment shown, gap 102' is filled with a non-conductive material, such as a plastic, and has a cylindrical outer surface matching the cylindrical outer surfaces of commutation tabs 72b', 74b'. Assembly 70' is shown with power brush 82, as heretofore described, having an angular dimension across its contacting face of about nine angular degrees. The six degrees difference between the dimension of power brush 82 and gap 102' results in a period of no energization between energization of phases A and B.

FIG. 12 is a phase energization profile for a motor 10 having a commutation assembly 70'. As seen in FIG. 12, for a period of about six angular degrees of rotation of rotor shaft 42, neither phase is energized. FIG. 13 is a static torque curve for a motor 10 energized as shown in FIG. 12. The periods of non-energization result in greater torque dips or drops between phases. With a shorter phase energization, rotor 40 must "coast" under its own momentum before the next phase energization. This may be desirable based upon the application and use of a specific motor 10.

FIGS. 11, 12 and 13 thus show how the dimension of gap 102 between commutation tabs 72b and 74b, and 76b and 78b affects the torque output of motor 10. A small gap 102 produces a more uniform torque profile, as seen in FIG. 10. As the angular dimension of gap 102 increases, a noticeable torque dip or drop is created between each phase.

As will be appreciated by those skilled in the art, the embodiment shown in FIGS. 11, 12 and 13 has "dead spots" wherein rotor 40 may come to rest when the motor is not in operation. Such a position is shown in FIG. 11 wherein power brush 82 is not in electrical contact with either commutation tab 72b' or commutation tab 74b'. In this position, nether phase-A windings 32a nor phase-B windings 32b can be energized. As a result, the motor will not start without some external motivation of rotor 40 to move it from such position. Conventional methods, such as a "parking magnet" may be used to prevent rotor 40 from coming to rest in such position.

The invention has heretofore been described with respect to a motor 10 of the type disclosed in U.S. Patent No. 5,852,334. A mechanical commutation system of the type heretofore described also finds advantageous application with motors such as those disclosed in commonly owned, pending U.S. Application No. 09/170,695, filed October 13, 1998 and U.S. Application No. 09/178,862 filed October 26, 1998, the disclosures of both being expressly incorporated herein by reference. Further, the invention also finds advantageous application with other, better known motor configurations, such as that shown in FIG. 14, that shows a two-phase, eight stator/four rotor motor with a stepped gap. Mechanical commutation assembly 70 may be connected to the windings of the motor shown in FIG. 14, in a manner as previously described, and provides the same results. Basically, a mechanical commutation assembly 70 as heretofore described may find advantageous application with any switched reluctance motor having phase energization overlap. The invention may also be used on switched reluctance motors that do not have phase energization overlap, so long as any "dead zone" is overcome by a "parking magnet" or the like, or a starting torque to move the rotor from such dead zone.

The foregoing are specific embodiments of the present invention. It should be appreciated that these embodiments are described for purposes of illustration only, and that numerous alterations and modifications may be practiced by those skilled in the art without departing from the spirit and scope of the invention. For example, while the invention was described with respect to a two-phase switched reluctance motor, the invention finds advantageous application with a motor having an N number of phases, wherein N is a whole number multiple, i.e., 1, 2, 3, 4 etc. Motors having more than two phases would require a pair of additional commutation rings for each additional phase. As will be appreciated, the tabs of all the commutation rings would need to be aligned with each other so as to contact the power brushes. Further the angular dimension of the tabs would need to be adjusted and the tabs would also need to be connected to their respective commutation ring in a manner which would electrically isolate the respective rings. Still further, while the present invention has been described with respect to a DC power source, the mechanical commutation system described above may also be used with an AC power source, provided direction diodes 132, 134 and their respective connections are removed from the circuits illustrated in FIGS. 5 through 8. It is intended that all such modifications and

alterations be included insofar as they come within the scope of the invention as claimed or the equivalents thereof.

Having described the invention, the following is claimed:

1. A switched reluctance motor, comprising:

a stator having a plurality of spaced apart, radially oriented, like stator poles that define a gap between adjacent stator poles;

windings for a first phase and a second phase wound about stator poles that are circumferentially separated by a winding and an associated stator pole of a different phase;

a rotor element mounted for rotation relative to said stator, said rotor element having a wide rotor pole having a wide rotor pole face and a narrow rotor pole having a narrow rotor pole face, said rotor poles being dimensioned such that energization of one of said phases causes a predetermined angular rotation of said rotor wherein a first portion of said angular rotation is created by said wide rotor pole being drawn into a minimum reluctance position relative to one of said energized stator poles and the other portion of said angular rotation is created by said narrow rotor pole being drawn into a minimum reluctance position with another of said energized stator poles, said wide rotor pole being in a minimum reluctance position when said narrow rotor pole is in a minimum reluctance position;

a pair of power brushes connectable to the leads of a power source;

a pair of first phase pick-up brushes connected to the windings of said first phase in a manner to energize the same;

a pair of second phase pick-up brushes connected to the windings of said second phase in a manner to energize the same; and

first phase and second phase connector plates mounted to said rotor for rotation therewith, said connector plates being dimensioned and disposed relative to said power brushes and said pick-up brushes to mechanically commutate said first and second phase windings.

2. A motor as defined in claim 1, wherein said rotor includes a rotor shaft and said connector plates are mounted on said rotor shaft.

3. A motor as defined in claim 2, wherein said connector plates are crenulated rings having spaced apart tabs thereon.

4. A motor as defined in claim 1, wherein:

said power brushes are connectable to a DC power source wherein one of said power brushes is a positive brush and one is a negative brush;

said first phase windings are connected in series wherein one of said first phase pick-up brushes is a positive brush and one is a negative brush; and

said second phase windings are connected in series wherein one of said first phase pick-up brushes is a positive brush and one is a negative brush.

5. A motor as defined in claim 4, wherein:

a first directional diode connects said negative first phase pick-up brush to said positive second phase pick-up brush to allow current induced in said first phase windings to flow into said second phase windings; and

a second directional diode connects said negative second phase pick-up brush to said positive first phase pick-up brush to allow current induced in said second phase winding to flow into said first phase windings.

6. A motor as defined in claim 1, wherein said power brushes are connectable to an AC power source.

7. A motor as defined in claim 6, wherein said first phase windings and said second phase windings are connected in series.

8. A motor as defined in claim 1, further comprising windings for a third phase, and a pair of third phase pick-up brushes connected to the windings of said third phase to energize the same.

9. A switched reluctance motor, comprising:

a stator having a plurality of spaced apart, radially oriented, like stator poles that define a gap between adjacent stator poles;

windings for two phases wound about said stator poles such that windings and stator poles of one phase are circumferentially separated by a winding and an associated stator pole of the other phase;

each phase having a positive and negative terminal for energizing the respective windings of such phase;

a rotor element mounted for rotation relative to said stator, said rotor element having a wide rotor pole having a wide rotor pole face and a narrow rotor pole having a narrow rotor pole face, said rotor poles being dimensioned such that energization of one of said phases causes a predetermined angular rotation of said rotor wherein a first portion of said angular rotation is created by said wide rotor pole being drawn into a minimum reluctance position relative to one of said energized stator poles and the other portion of said angular rotation is created by said narrow

rotor pole being drawn into a minimum reluctance position with another of said energized stator poles, said wide rotor pole being in a minimum reluctance position when said narrow rotor pole is in a minimum reluctance position;

conductive elements rotatable with said rotor, said elements being electrically connected to said positive and negative terminals of said phase windings; and

power leads engageable with said conductive elements to alternately energize said first phase and second phase as said rotor rotates.

10. A switched reluctance motor, comprising:

a stator having a plurality of spaced apart, radially oriented, like stator poles that define a gap between adjacent stator poles;

windings for a first phase and a second phase wound about stator poles that are circumferentially separated by a winding and an associated stator pole of a different phase;

a rotor element mounted for rotation relative to said stator, said rotor element having a plurality of spaced apart rotor poles, said rotor poles being dimensioned such that energization of one of said phases causes a predetermined angular rotation of said rotor;

a pair of power brushes connectable to the leads of a power source;

a pair of first phase pick-up brushes connected to the windings of said first phase in a manner to energize the same;

a pair of second phase pick-up brushes connected to the windings of said second phase in a manner to energize the same; and

first phase and second phase connector plates mounted to said rotor for rotation therewith, said connector plates being dimensioned and disposed relative to said power brushes and said pick-up brushes to mechanically commutate said first and second phase windings.

11. A motor as defined in claim 10, wherein said rotor has a wide rotor pole having a wide rotor pole face and a narrow rotor pole and a narrow rotor pole face, and wherein a first portion of said angular rotation is created by said wide rotor pole being drawn into a minimum reluctance position relative to one of said energized stator poles and the other portion of said angular rotation is created by said narrow rotor pole being drawn into a minimum reluctance position with another of said

energized stator poles, said wide rotor pole being in a minimum reluctance position when said narrow rotor pole is in a minimum reluctance position.

12. A motor as defined in claim 11, wherein said rotor includes a rotor shaft and said connector plates are mounted on said rotor shaft.

13. A motor as defined in claim 12, wherein said connector plates are crenelated rings having spaced apart tabs thereon.

14. A motor as defined in claim 10, wherein said rotor has a plurality of like rotor poles, each of said rotor poles having a rotor pole face that defines a stepped gap with said stator poles.

15. A motor as defined in claim 11, wherein:

said power brushes are connectable to a DC power source wherein one of said power brushes is a positive brush and one is a negative brush;

said first phase windings are connected in series wherein one of said first phase pick-up brushes is a positive brush and one is a negative brush; and

said second phase windings are connected in series wherein one of said first phase pick-up brushes is a positive brush and one is a negative brush.

16. A motor as defined in claim 15, wherein:

a first directional diode connects said negative first phase pick-up brush to said positive second phase pick-up brush to allow current induced in said first phase winding to flow into said second phase windings; and

a second directional diode connects said negative second phase pick-up brush to said positive first phase pick-up brush to allow current induced in said second phase winding to flow into said first phase windings.

17. A switched reluctance motor, comprising:

a stator having a plurality of spaced apart, radially oriented, like stator poles;

windings for an "N" number of phases wound about said stator poles;

a rotor mounted for rotation relative to said stator, said rotor having a plurality of rotor poles, said rotor poles being dimensioned such that energization of each of said N number of phases causes a predetermined angular rotation of said rotor;

a pair of stationary power brushes connectable to leads of a power source;

a pair of stationary phase pick-up brushes for each phase of said N number of phases, said pick-up brushes connected to the respective windings of said each phase in a manner to energize the same;

a pair of connector plates for said each phase, said connector plates being mounted to said rotor for rotation therewith, said pair of connector plates being disposed relative to said power brushes and the pick-up brush so as to electrically connect said power brushes with said pick-up brush to produce a current path through said each phase when in said rotor is at specific angular positions.

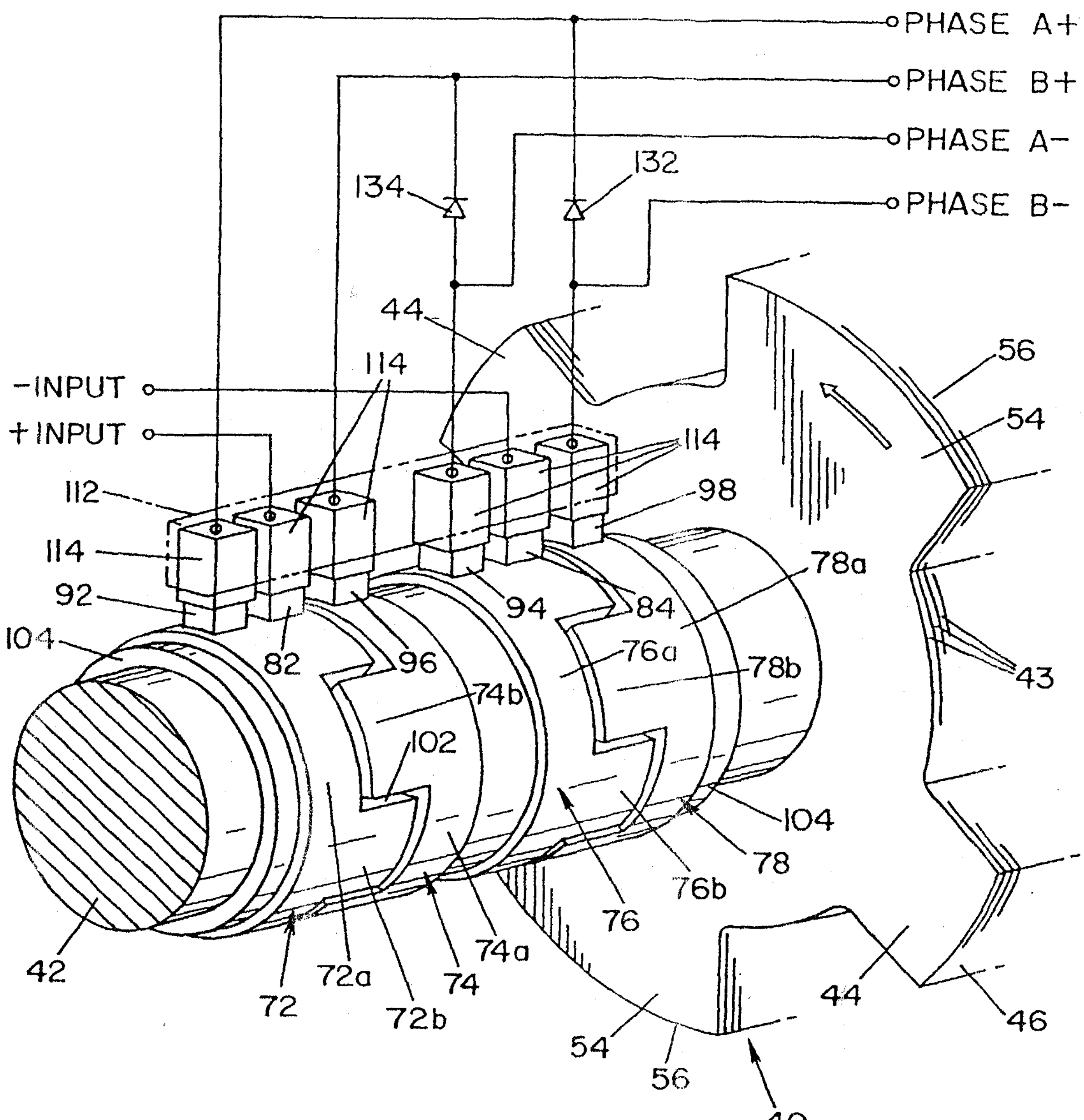
18. A motor as defined in claim 17, wherein "N" is a whole number multiple.

19. A motor as defined in claim 18, wherein said connector plates are continuous, annular bands having tabs connected thereto.

20. A motor as defined in claim 19, wherein annular bands are cylindrical rings.

21. A motor as defined in claim 20, wherein one of said power brushes and one of said pick-up brushes is in physical contact with each of said connector plates.

22. A motor as defined in claim 21, wherein pick-up brushes are in continuous physical contact with said cylindrical rings and said power brushes are in physical contact with said tabs on said cylindrical rings when said rotor is at said specific angular positions.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PHASE B+
PHASE A-
PHASE B-
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132
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+INPUT
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114
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104
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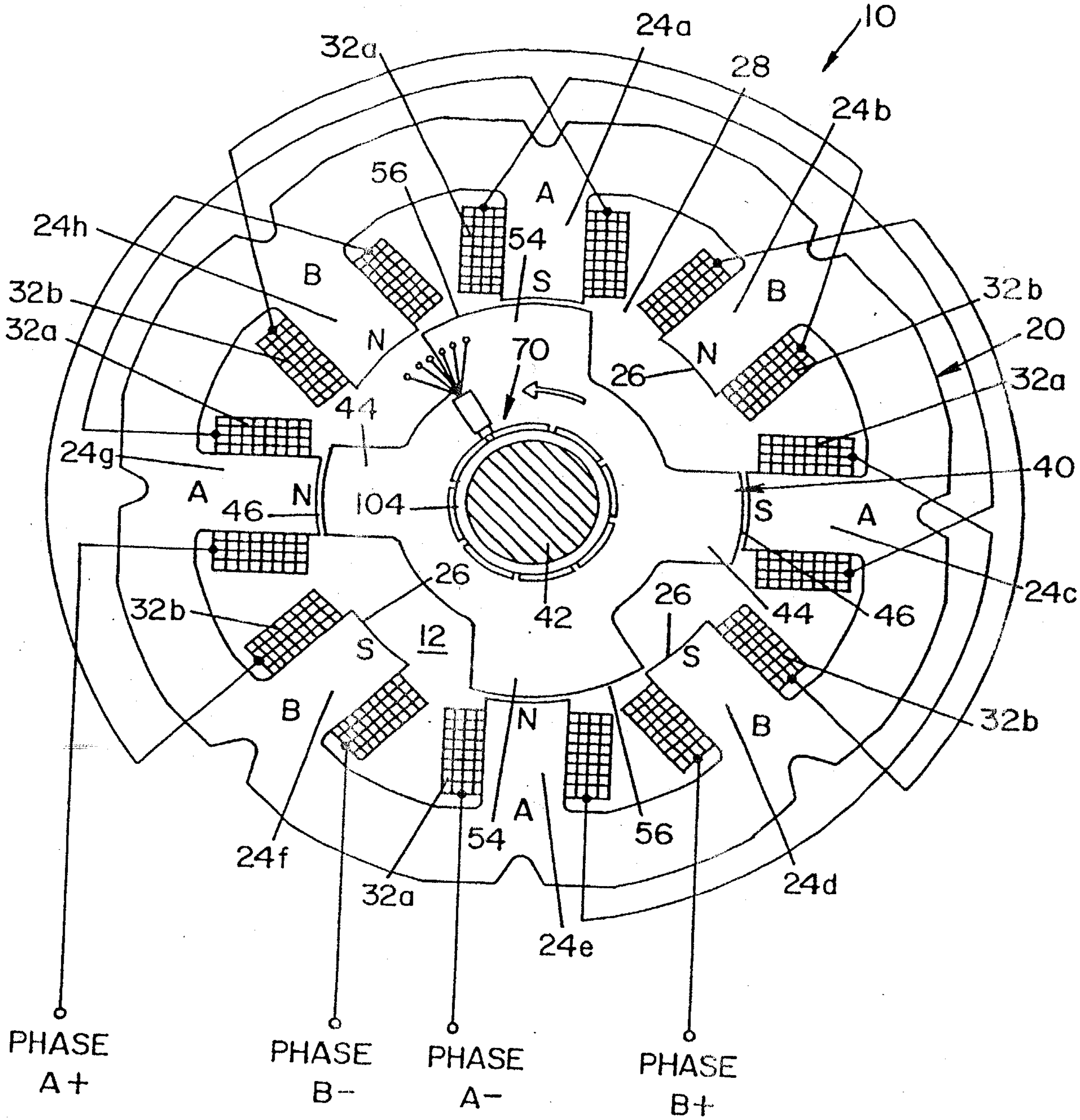
84
98
56
54
43
78a
76a
78b
74b
102
104
78
76b
76
42
72
72a
72b
74
74a
54
56
40
44
46

FIG. 1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28
24b
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56
A
54
S
24h
B
N
32b
32a
B
N
26
32b
20
32a
70
44
40
24g
A
N
46
104
S
A
26
42
46
24c
32b
S
12
44
26
S
B
N
B
32b
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56
24f
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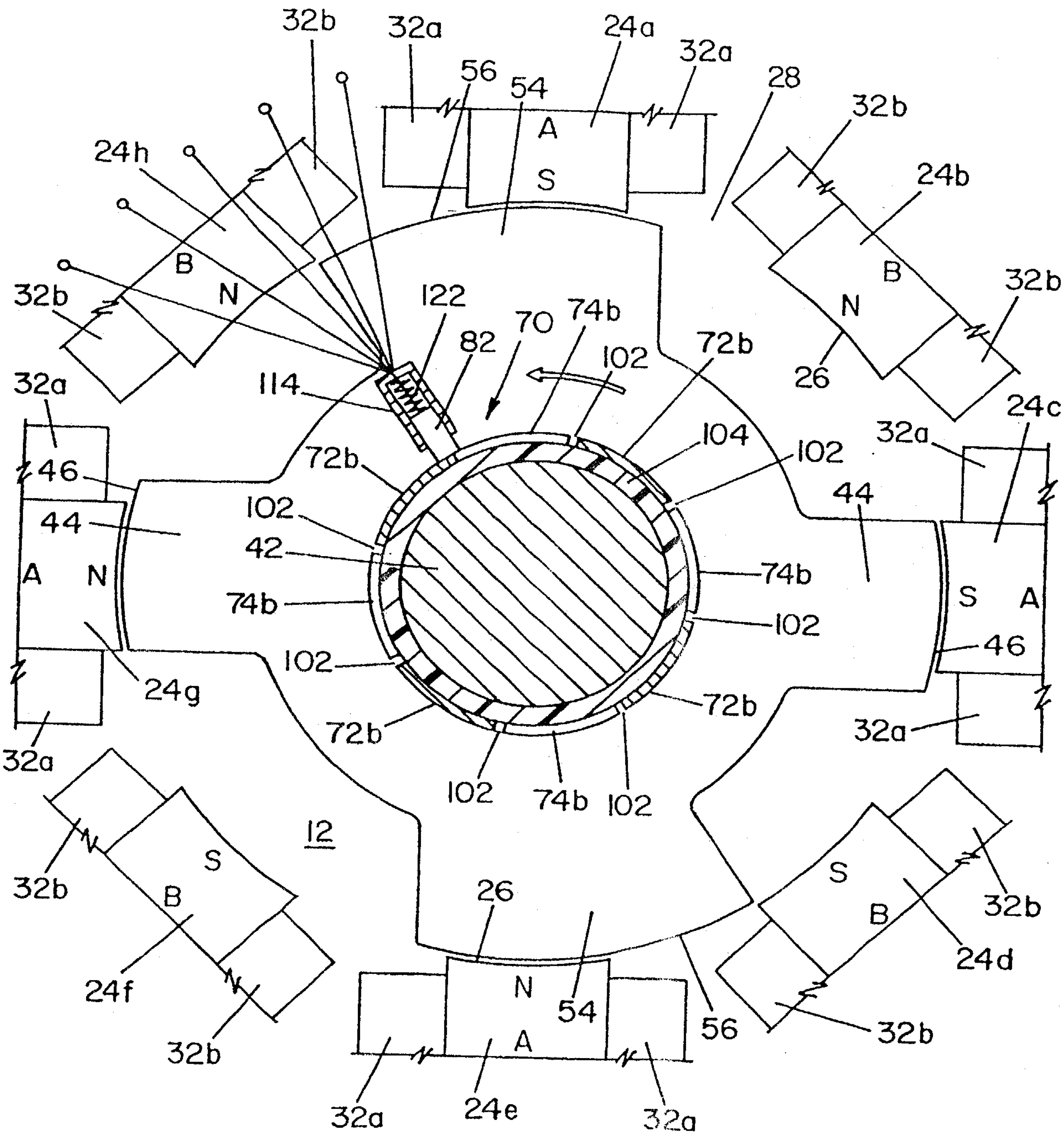
24e
24d
PHASE A+
PHASE B−
PHASE A−
PHASE B+

FIG. 2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32b
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N
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72b
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24c
32a
72b
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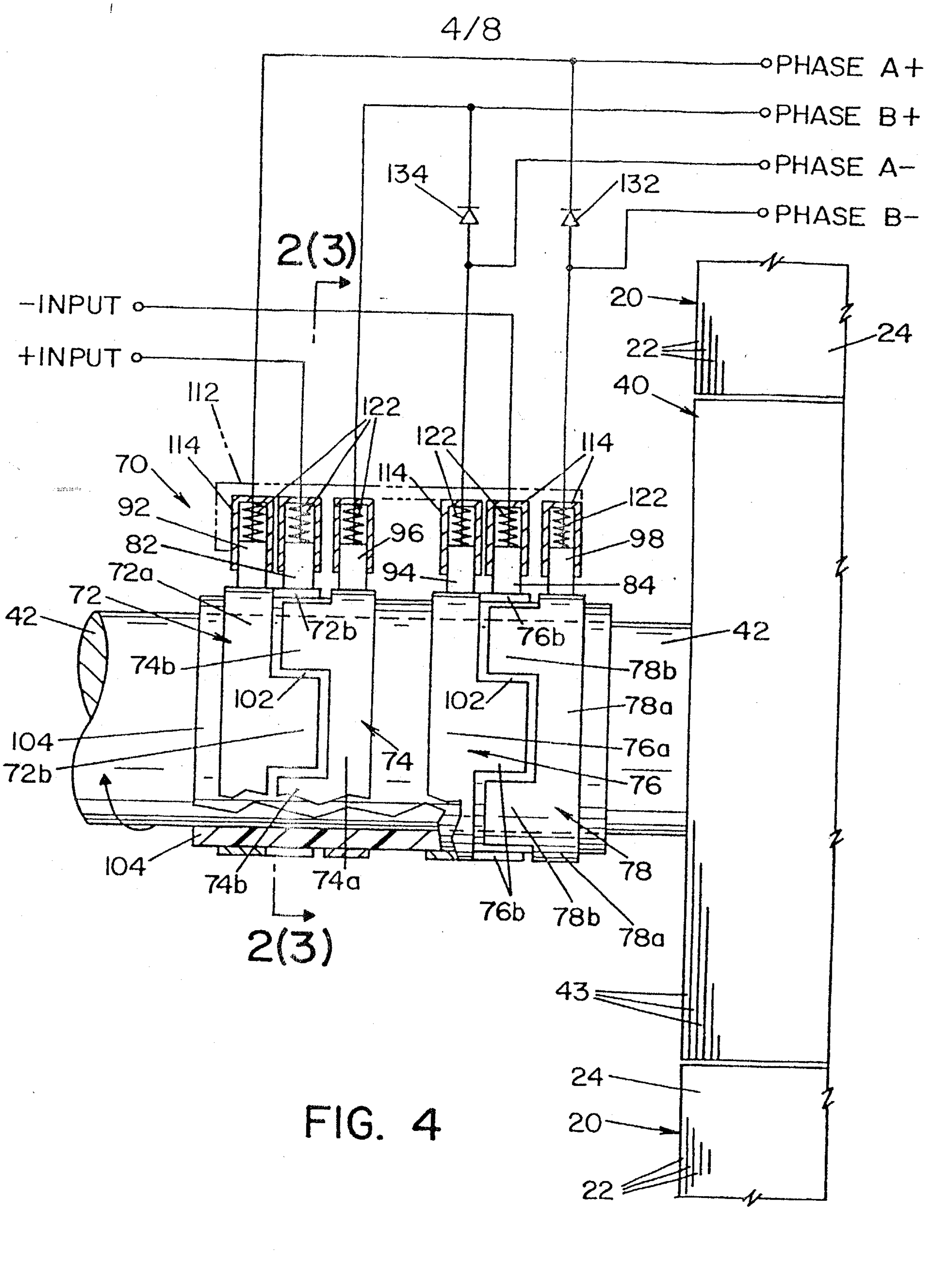
32a
46
44
102
44
42
A
N
74b
74b
S
A
102
46
102
24g
72b
72b
32a
32a
102
74b
102
12
S
32b
S
B
32b
26
B
24d
24f
N
54
56
32b
A
32b
32a
24e
32a

FIG. 3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PHASE B+
PHASE A-
PHASE B-
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132
2(3)
-INPUT
+INPUT
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40
112
122
114
70
92
82
72a
72
42
96
94
84
98
72b
76b
74b
78b
102
78a
104
76a
74
76
74a
78
2(3)
43

FIG. 4

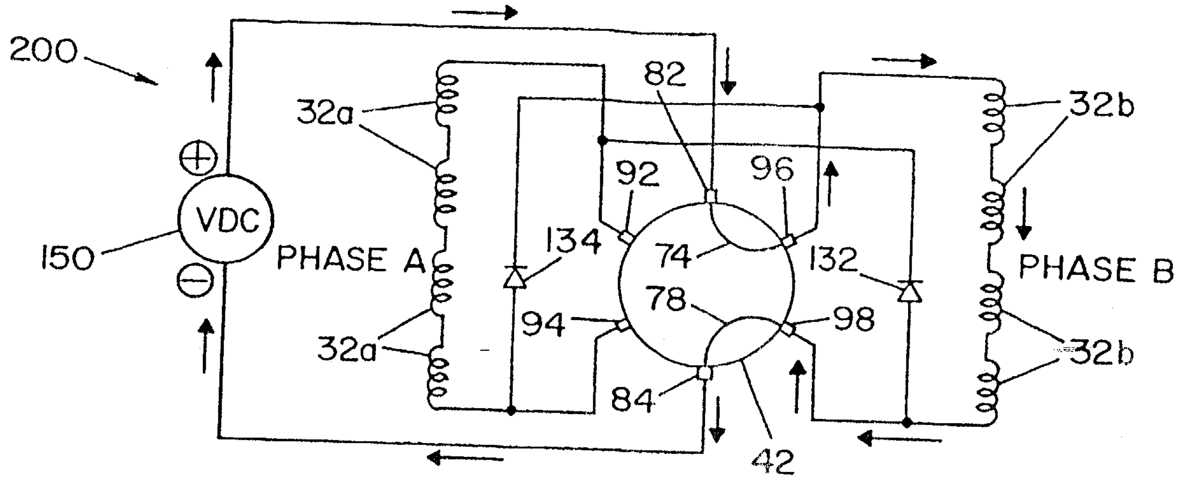


FIG. 5

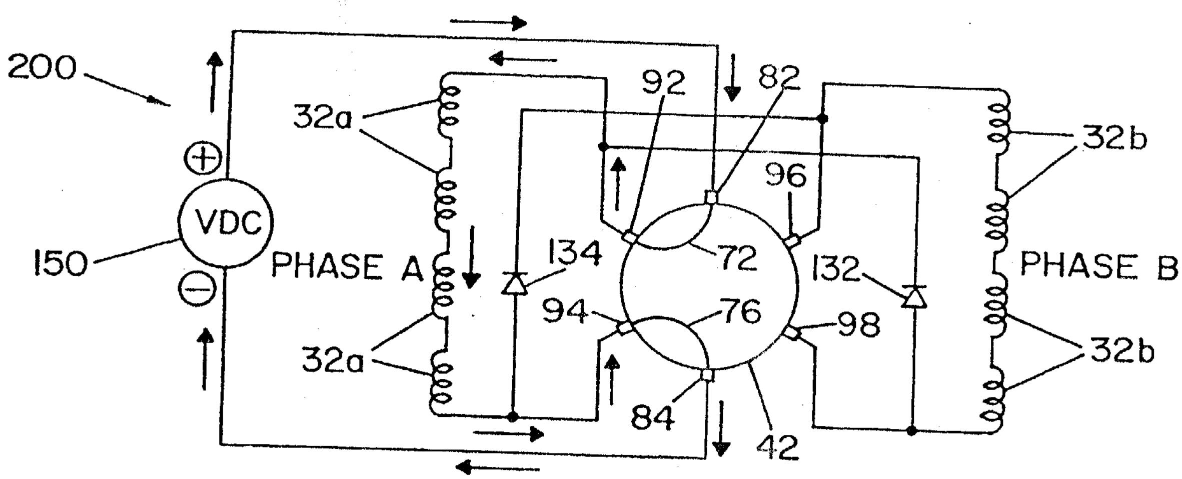


FIG. 6

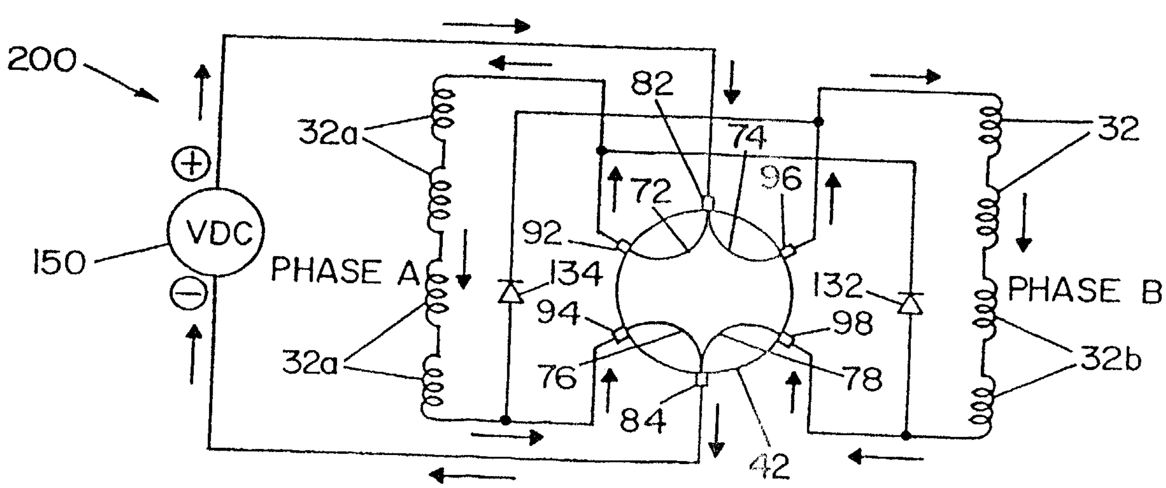


FIG. 7

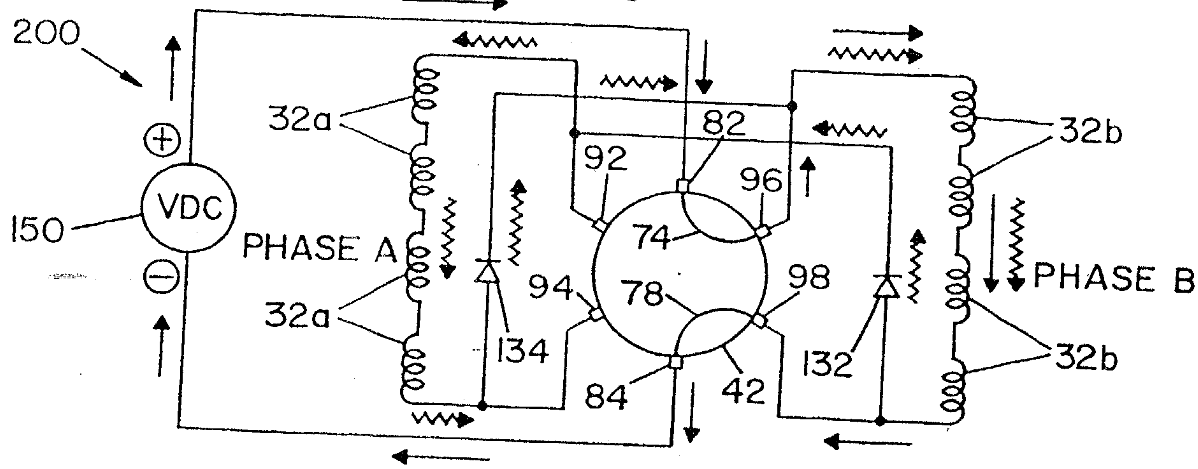

200
150
VDC
32a
32a
PHASE A
134
92
94
82
74
78
84
42
96
98
132
32b
32b
PHASE B

FIG. 8

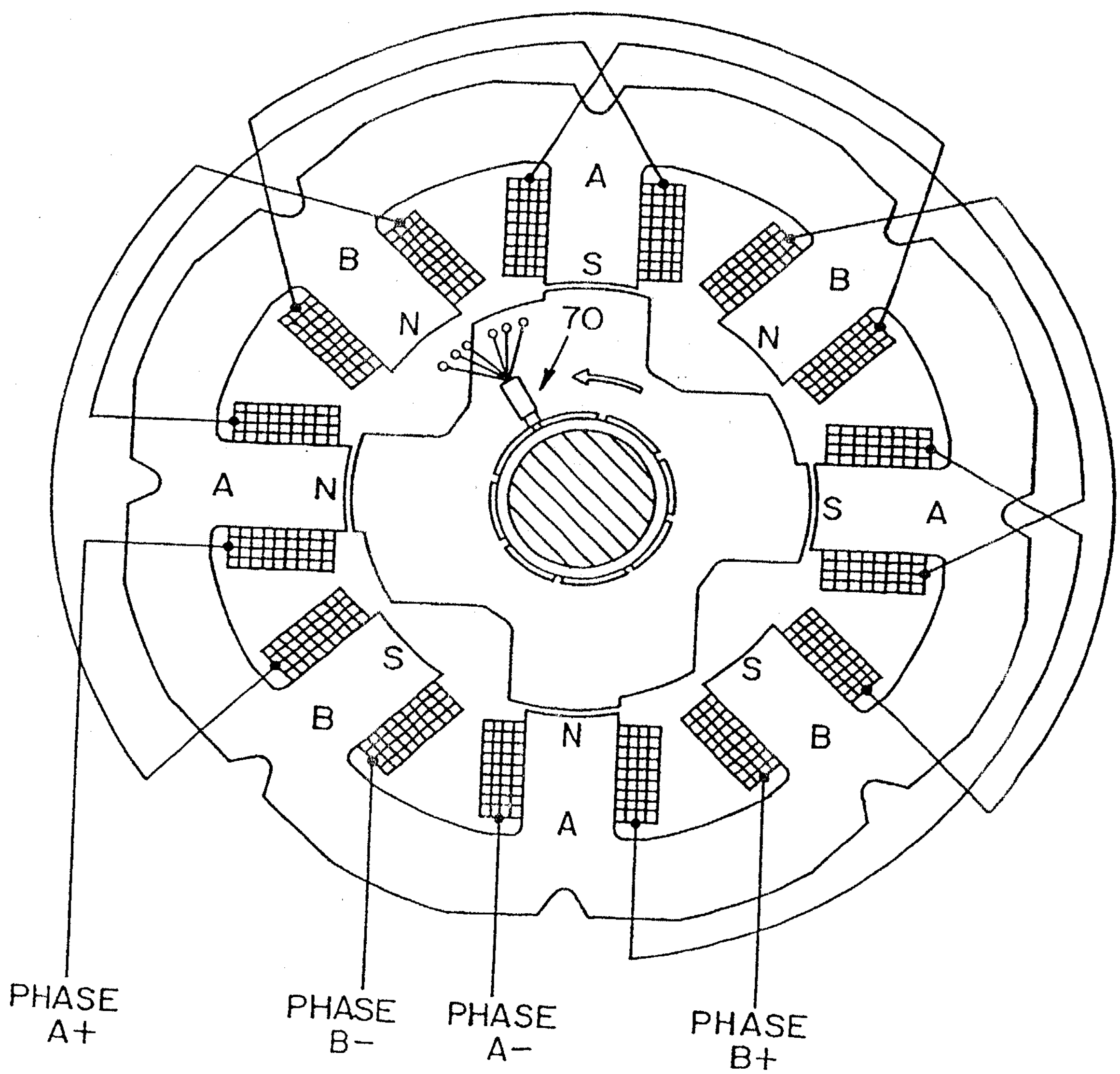

A
S
B
N
B
N
70
A
N
S
A
S
B
S
B
N
A
PHASE A+
PHASE B-
PHASE A-
PHASE B+

FIG. 14

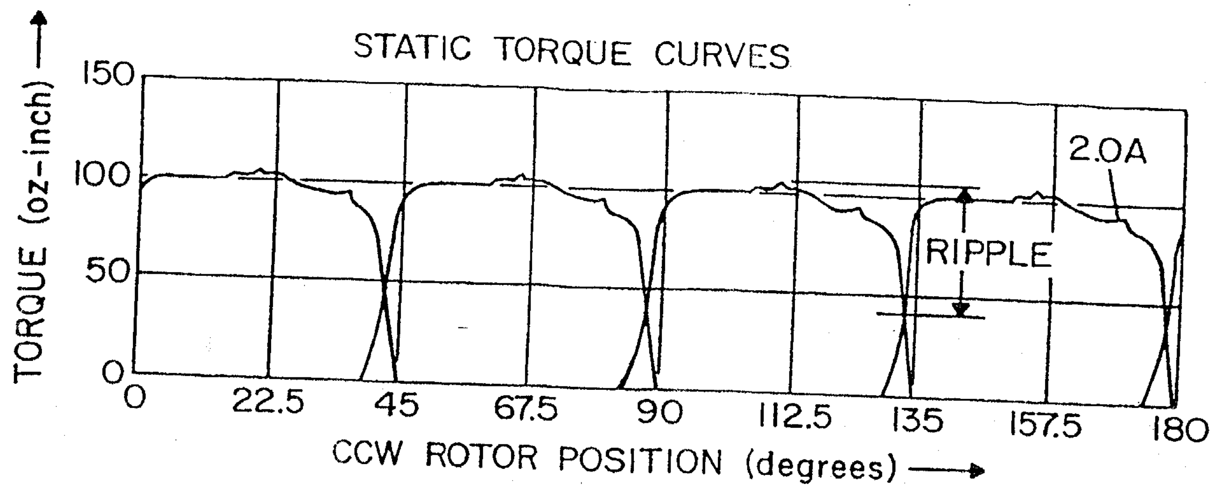


FIG. 10

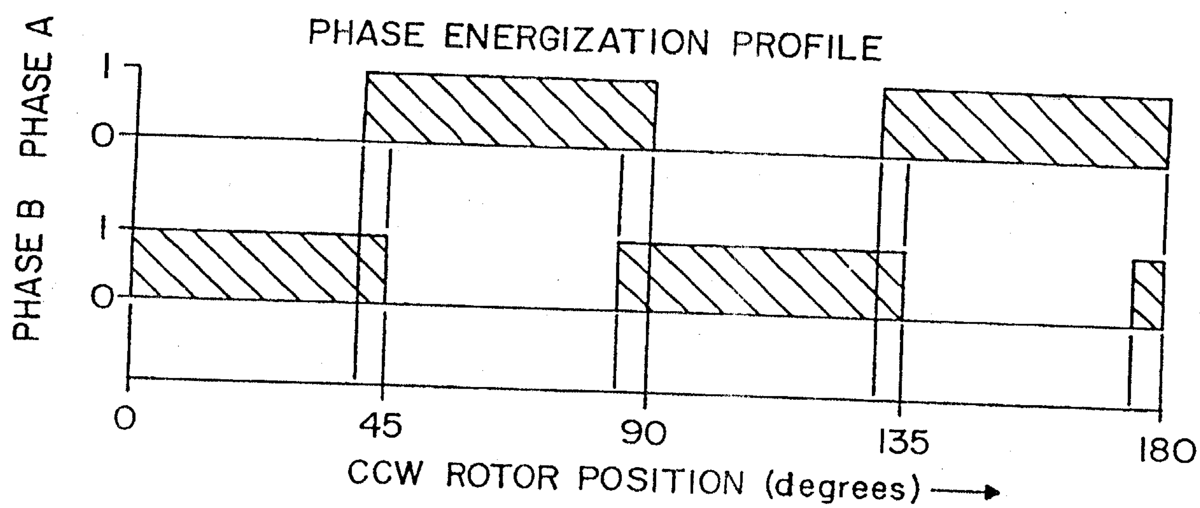


FIG. 9

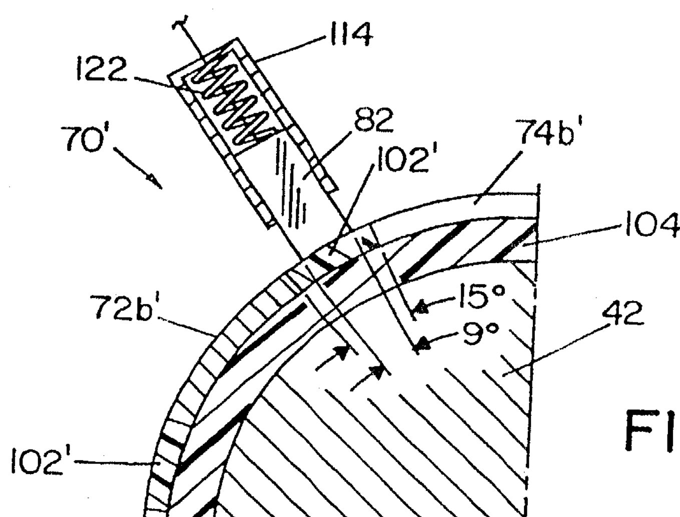


FIG. 11

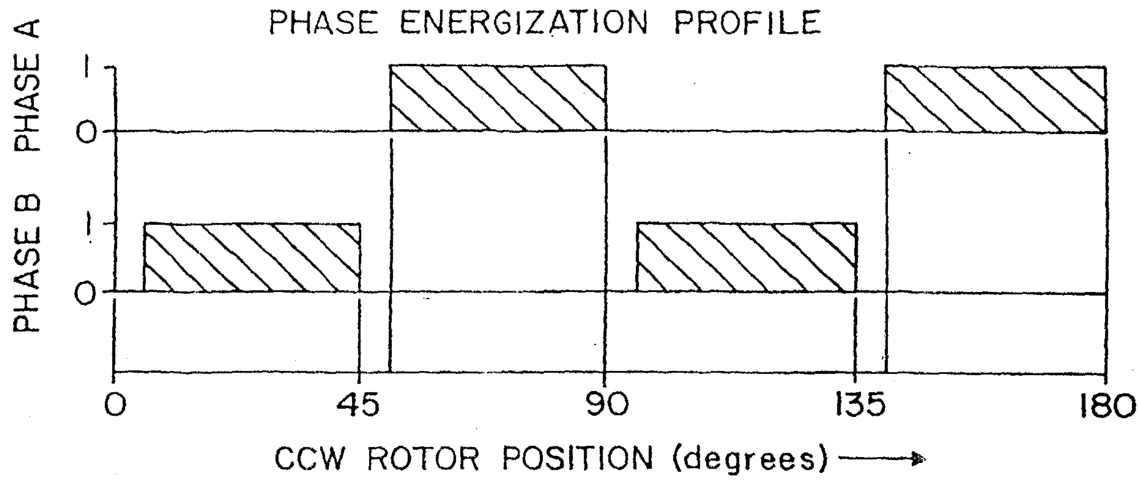

PHASE ENERGIZATION PROFILE
PHASE A
PHASE B
1
0
1
0
0
45
90
135
180
CCW ROTOR POSITION (degrees)

FIG. 12

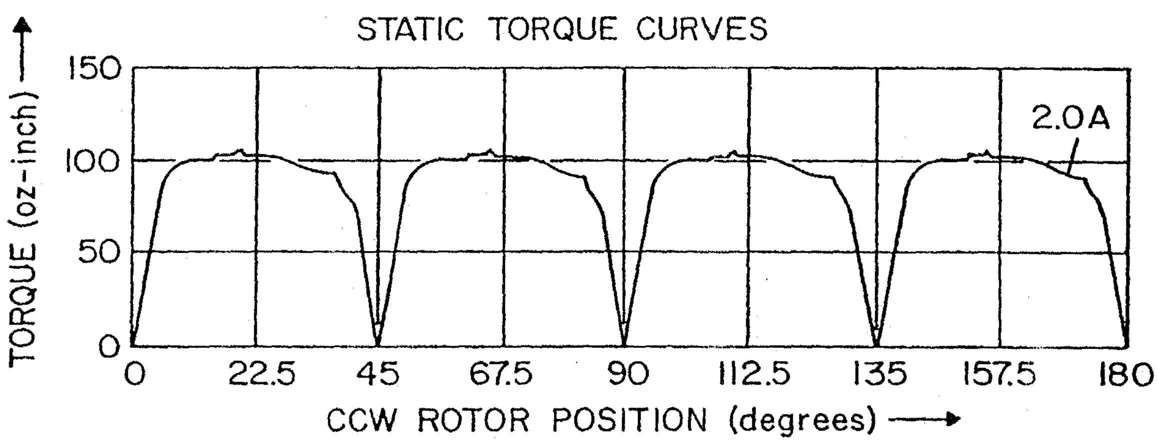

STATIC TORQUE CURVES
TORQUE (oz-inch)
150
100
50
0
2.0A
0
22.5
45
67.5
90
112.5
135
157.5
180
CCW ROTOR POSITION (degrees)

FIG. 13

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/34327

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :Please See Extra Sheet.
US CL :310/68R, 128, 180, 232, 233
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 310/68R, 128, 179, 180, 231, 232, 233, 234

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

USPTO APS JPO, EPO
search terms: Pengov Wayne, commutator, notch, diode, brush

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,852,334 A (PENGOV) 22 December 1998 (22.12.1998), col. 7, lines 3-17 and Figs. 1-6.	1-22
Y	US 5,623,177 A (DIMATTEO et al) 22 April 1997 (22.04.1997), col. 1, lines 42-45.	1-22
Y	US 4,142,119 A (MADEY) 27 February 1979 (27.02.1979), col. 5, lines 13-68 Figs. 2 and 3.	1-22
Y	US 4,425,536 A (LARSEN) 10 January 1984 (10.01.1984), Figs. 1-9 and 11-12.	1-13, 15-22
Y	US 5,122,697 A (HORST) 16 June 1992 (16.6.1992) figs. 1, 5-10 and 13-14.	14

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance		
"E"	earlier document published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed	"&"	document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 FEBRUARY 2001	19 APR 2001

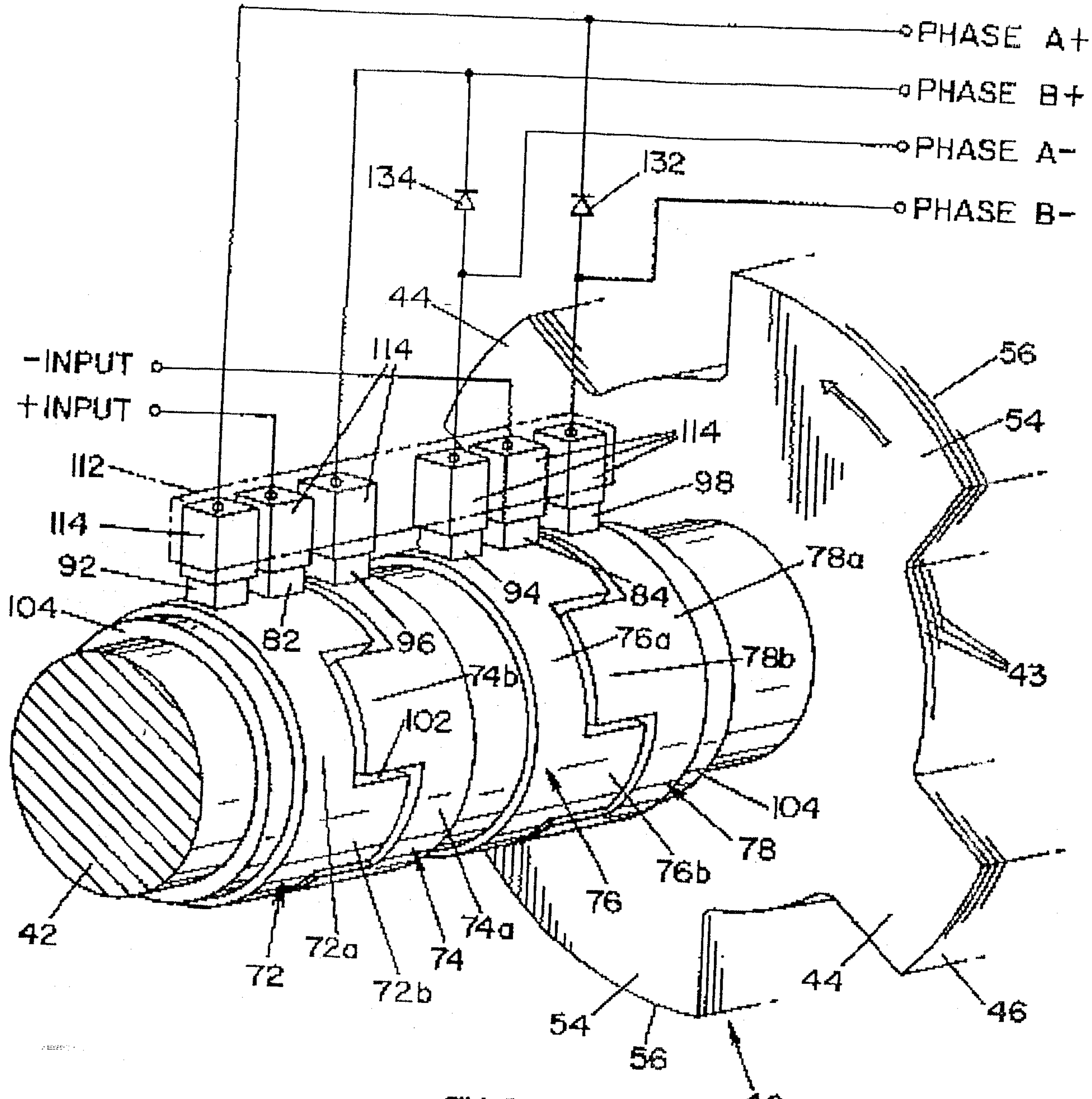
Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT	GUILLERMO PEREZ

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/34327

A. CLASSIFICATION OF SUBJECT MATTER:
IPC (7):

H02K 11/00, 13/00, 47/08, 47/16, 47/28, 3/00, 23/02; H01R 39/08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132
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102
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72b
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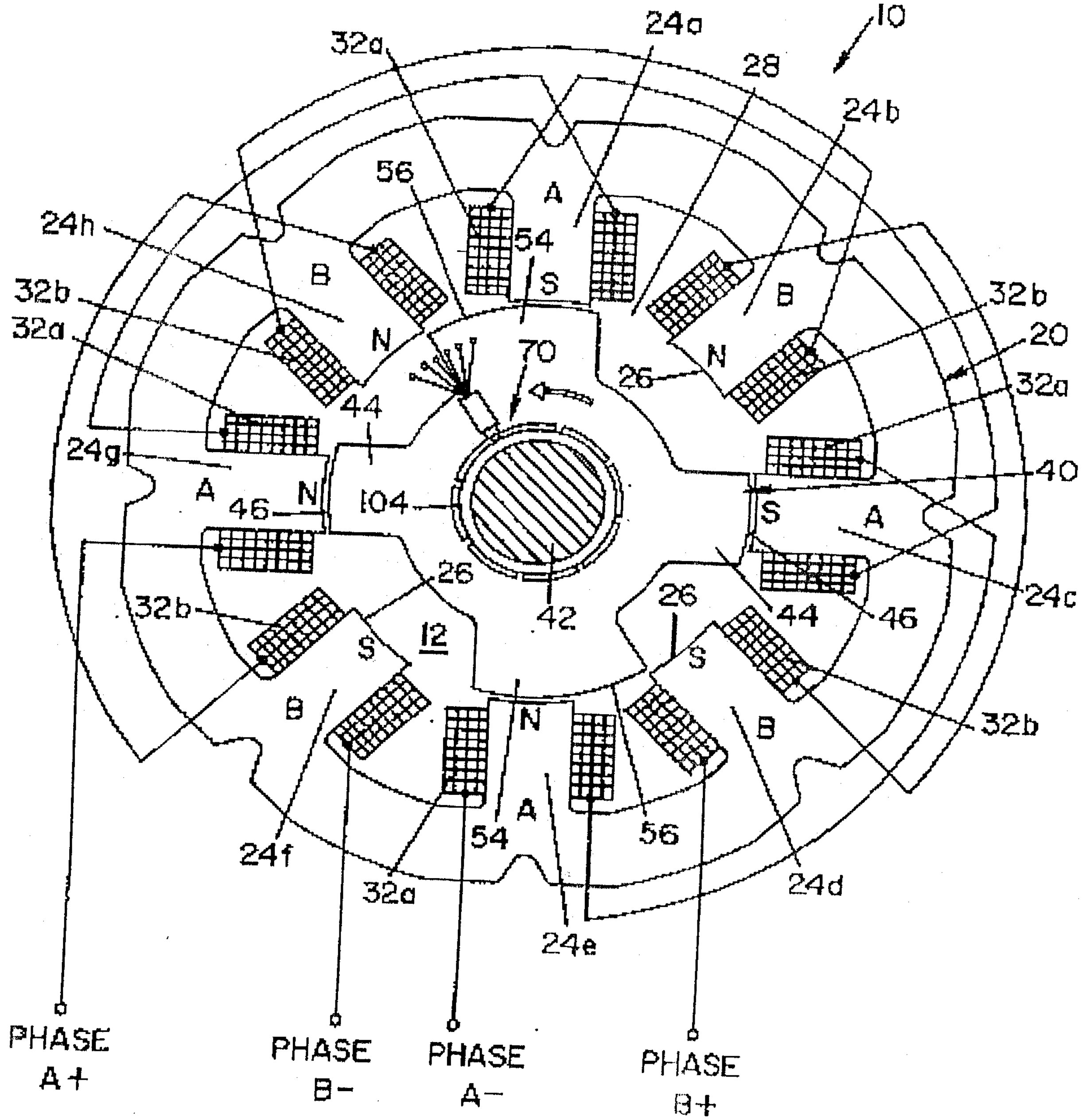
56
40

FIG. 1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24a
32a
28
24b
56
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54
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B
S
B
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N
N
32b
32a
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20
32a
44
24g
A
N
104
40
46
S
A
26
24c
44
46
32b
26
42
12
S
26
S
B
B
32b
N
B
24f
54
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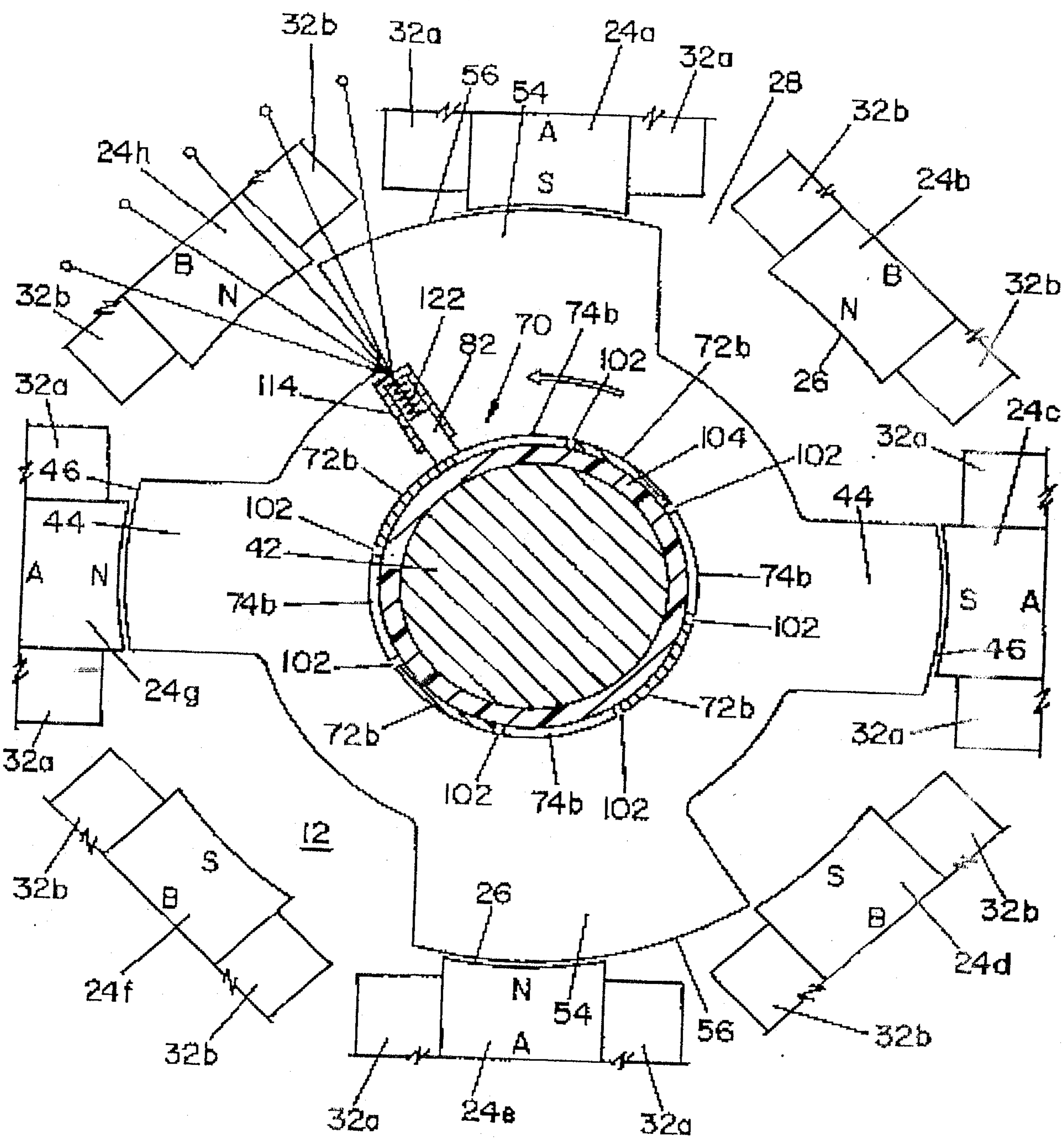
32a
24d
24e
PHASE
A+
PHASE
B−
PHASE
A−
PHASE
B+

FIG. 2


32b
32a
24a
32a
56
54
28
A
S
32b
24h
24b
B
N
B
32b
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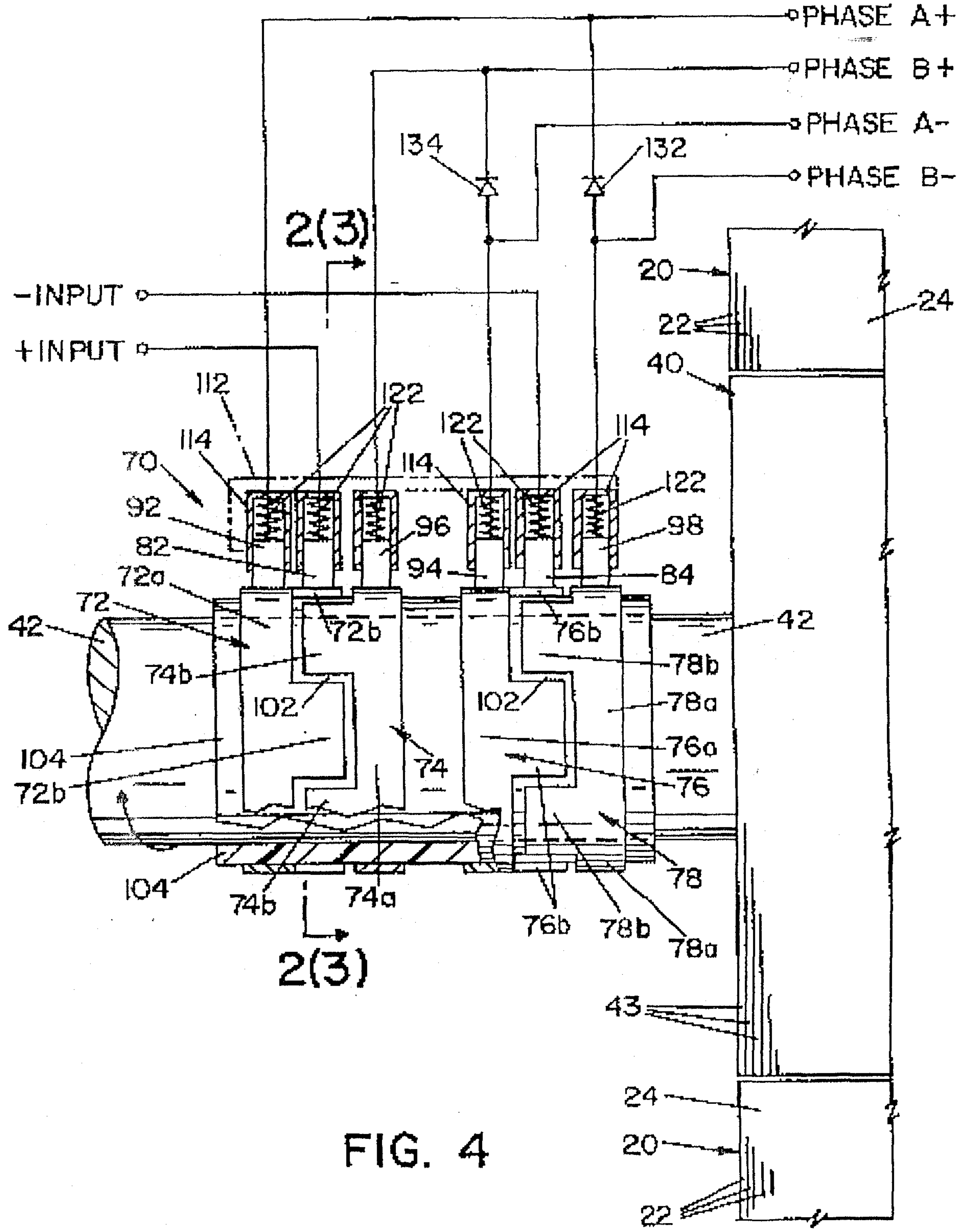
122
70
74b
26
114
82
102
72b
32a
104
102
24c
46
72b
32a
44
44
102
42
A
N
74b
S
A
74b
102
46
102
24g
72b
72b
32a
32a
102
74b
102
12
32b
S
32b
B
S
26
B
24d
24f
N
54
56
32b
32b
A
32a
24e
32a

FIG. 3


PHASE A+
PHASE B+
PHASE A-
PHASE B-
134
132
2(3)
-INPUT
+INPUT
20
22
24
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112
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114
70
92
82
72a
72
42
96
94
98
84
72b
76b
74b
78b
102
78a
104
76a
74
76
78
74a
78a
43

FIG. 4

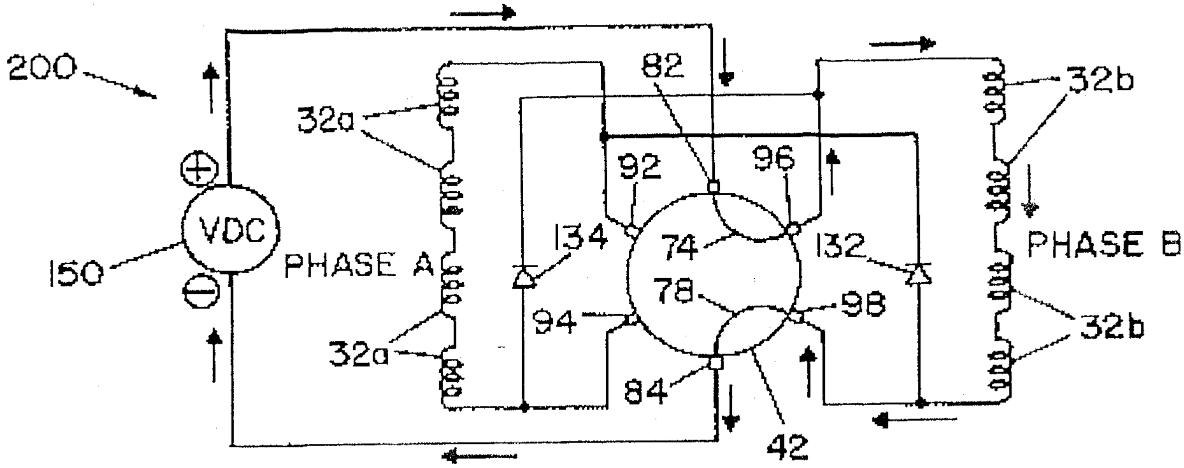


FIG. 5

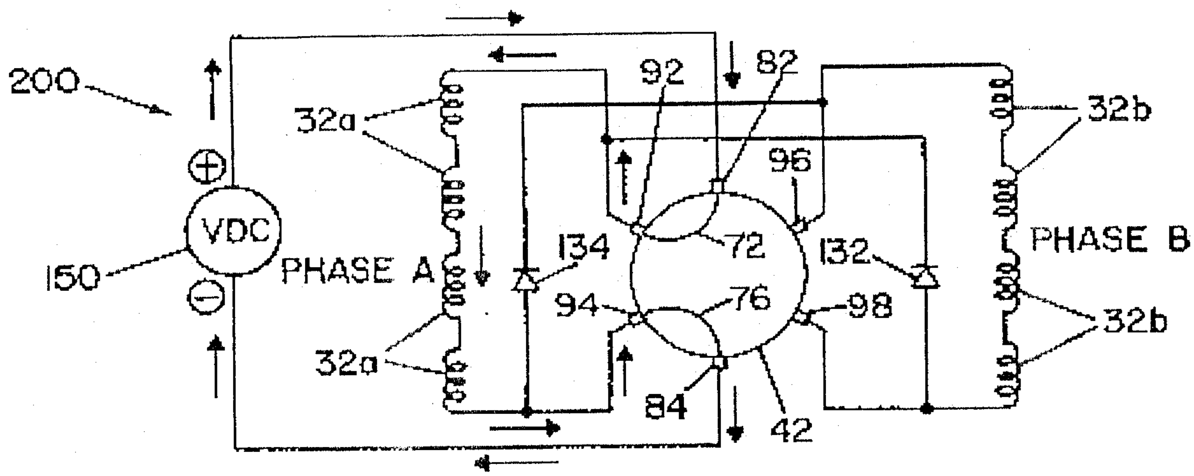


FIG. 6

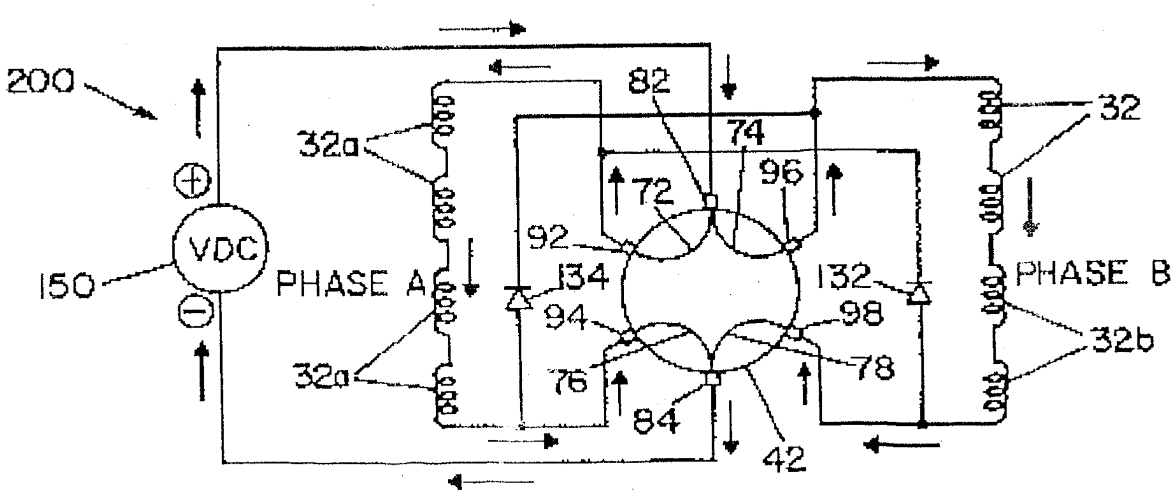


FIG. 7

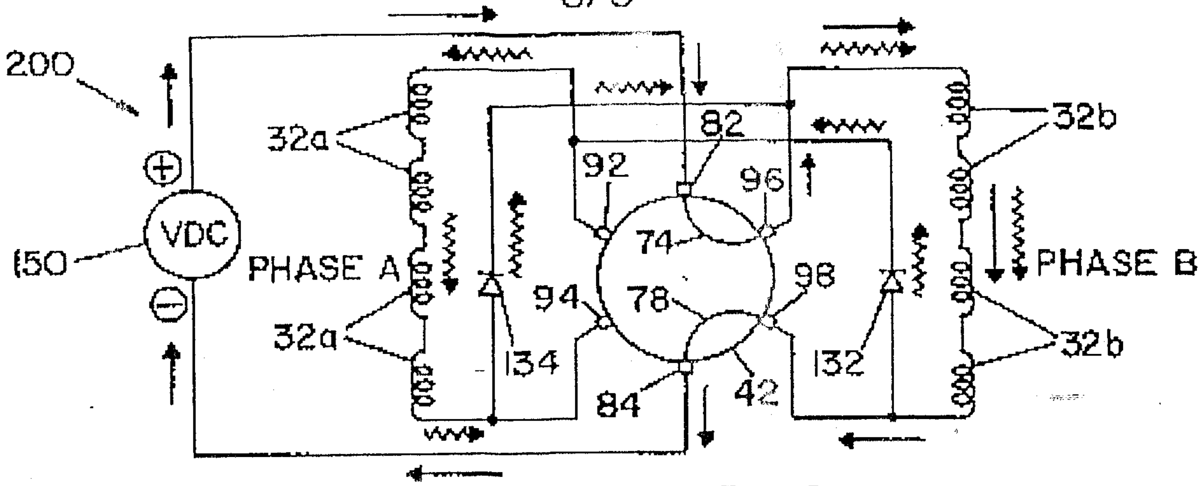
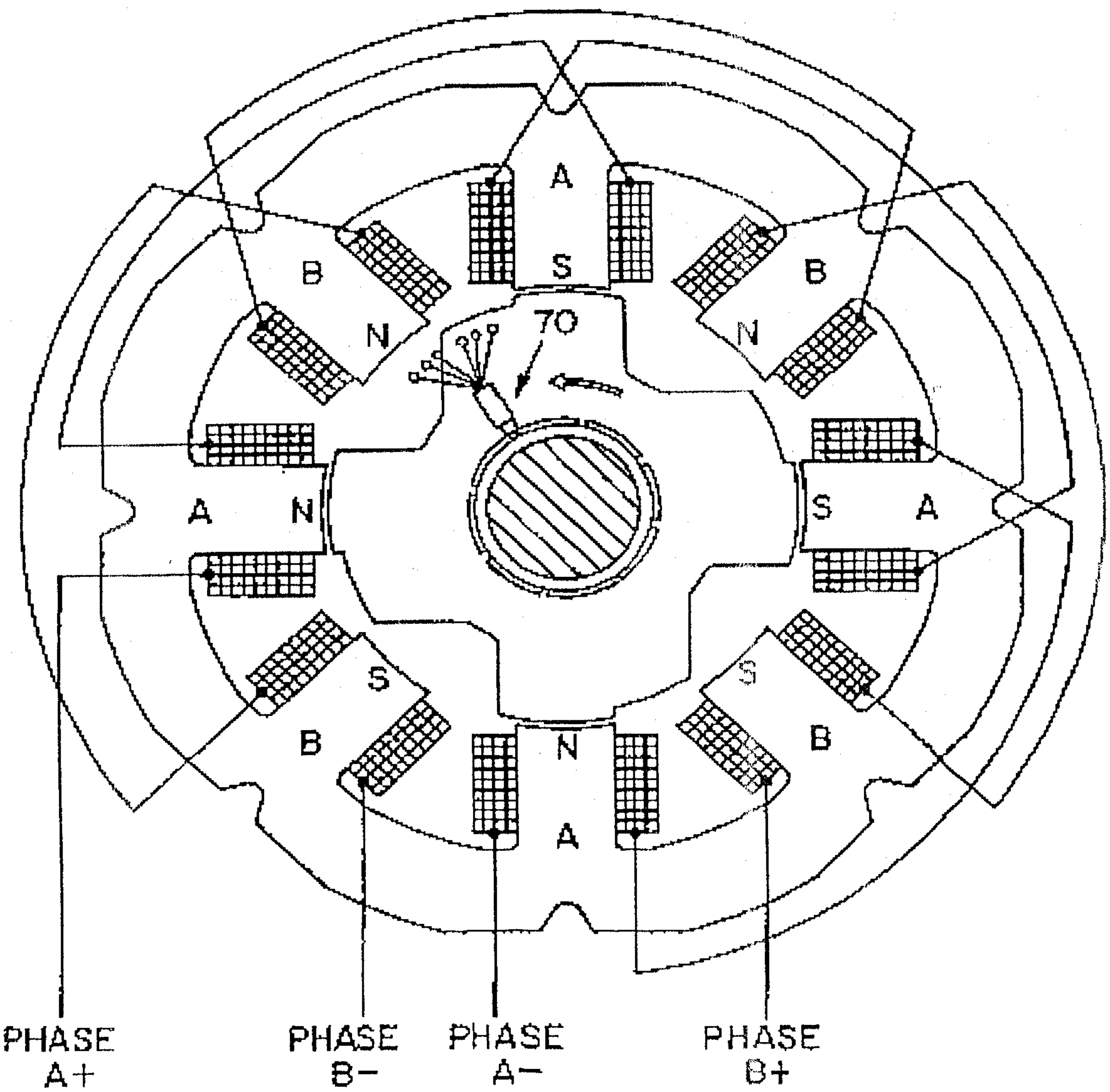

200
32a
32a
VDC
150
PHASE A
32a
134
92
94
82
74
78
84
42
96
98
132
32b
PHASE B
32b

FIG. 8


A
S
B
N
B
N
70
A
N
S
A
S
B
S
B
N
A
PHASE A+
PHASE B−
PHASE A−
PHASE B+

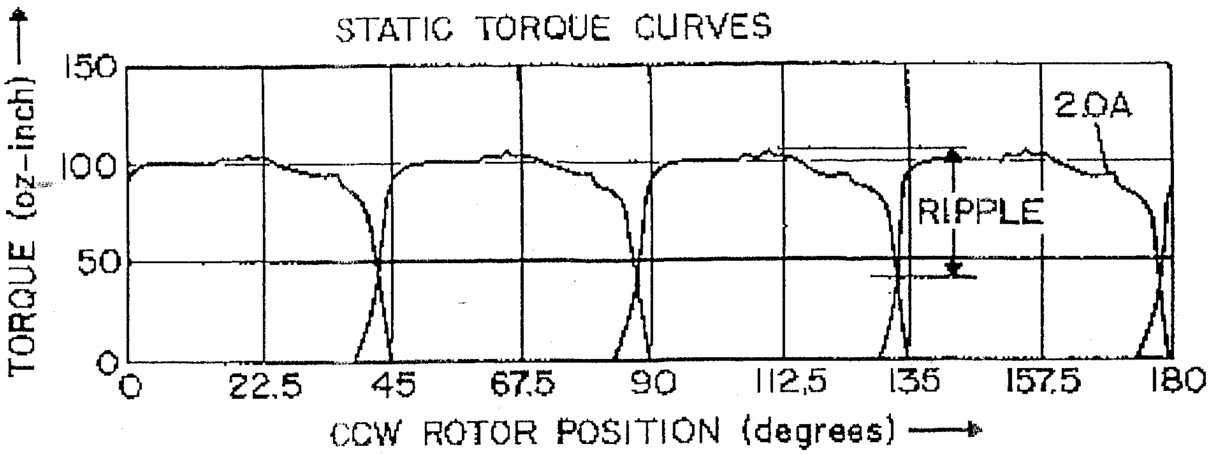


FIG. 10

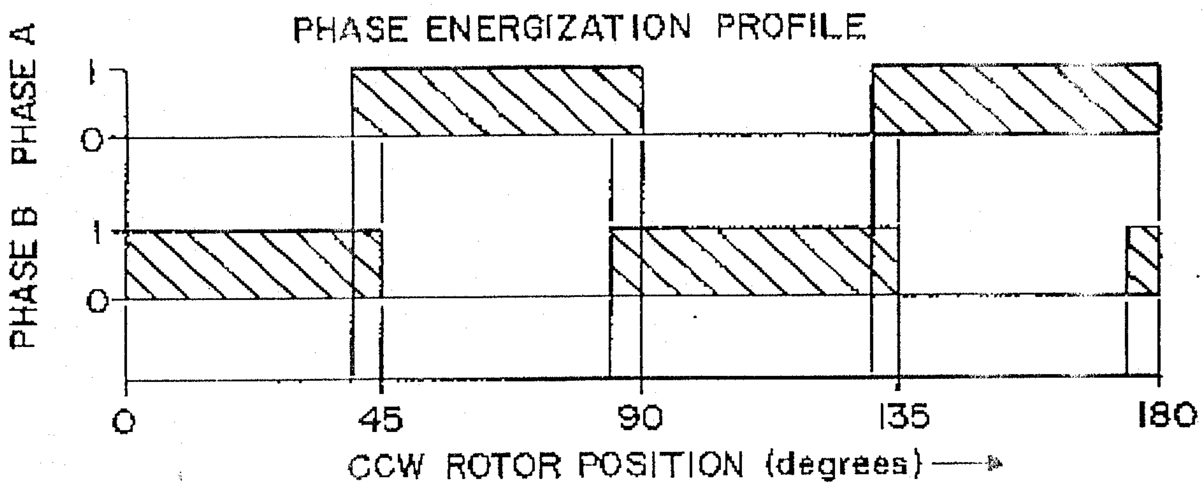


FIG. 9

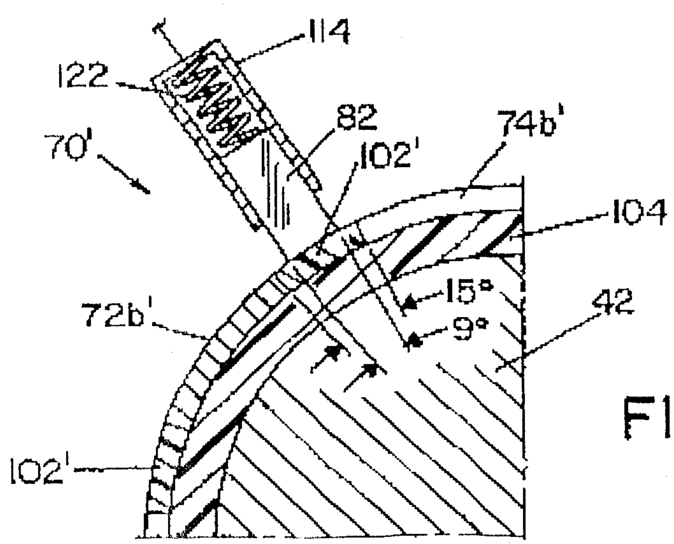


FIG. 11